MERCURY CONTROL WITH THE ADVANCED HYBRID PARTICULATE COLLECTOR

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MERCURY CONTROL WITH THE ADVANCED HYBRID PARTICULATE COLLECTOR

ABSTRACT

This project was awarded under U.S. Department of Energy (DOE) National Energy Technology Laboratory (NETL) Program Solicitation DE-PS26-00NT40769 and specifically addresses Technical Topical Area 4 – Testing Novel and Less Mature Control Technologies on Actual Flue Gas at the Pilot Scale. The project team includes the Energy & Environmental Research Center (EERC) as the main contractor; W.L. Gore & Associates, Inc., as a technical and financial partner; and the Big Stone Power Plant operated by Otter Tail Power Company, which will host the field testing portion of the research.

Since 1995, DOE has supported development of a new concept in particulate control, called the advanced hybrid particulate collector (AHPC). The AHPC has been licensed to W.L. Gore & Associates, Inc., and is now marketed as the Advanced Hybrid™ by Gore. The AHPC combines the best features of electrostatic precipitators (ESPs) and baghouses in a unique configuration, providing major synergism between the two collection methods, both in the particulate collection step and in the transfer of dust to the hopper. The AHPC provides ultrahigh collection efficiency, overcoming the problem of excessive fine-particle emission with conventional ESPs, and it solves the problem of reentrainment and re-collection of dust in conventional baghouses. The AHPC appears to have unique advantages for mercury control over baghouses or ESPs as an excellent gas–solid contactor.

The objective of the three-task project is to demonstrate 90% total mercury control in the AHPC at a lower cost than current mercury control estimates. The approach includes bench-scale batch testing that ties the new work to previous results and links results with larger-scale pilot testing with real flue gas on a coal-fired combustion system, pilot-scale testing on a coal-fired combustion system with both a pulse-jet baghouse and an AHPC to prove or disprove the research hypotheses, and field demonstration pilot-scale testing at a utility power plant to prove scaleup and demonstrate longer-term mercury control.

This project, if successful, will demonstrate at the pilot-scale level a technology that would provide a cost-effective technique to accomplish control of mercury emissions and, at the same time, greatly enhance fine particulate collection efficiency. The technology can be used to retrofit systems currently employing inefficient ESP technology as well as for new construction, thereby providing a solution to a large segment of the U.S. utility industry as well as other industries requiring mercury control.

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AHPC	advanced hybrid particulate collector
A/C	air-to-cloth
CEM	continuous emission monitor
CVAA	cold-vapor atomic absorption
DOE	U.S. Department of Energy
EB	eastern bituminous
EERC	Energy & Environmental Research Center
EPA	U.S. Environmental Protection Agency
ESP	electrostatic precipitator
FGD	flue gas desulfurization
IAC	iodine-impregnated activated carbon
LOI	loss on ignition
NETL	National Energy Technology Laboratory
pc	pulverized coal
PJBH	pulse-jet bag house
PRB	Powder River Basin
PTC	particulate test combustor
WSB	western subbituminous

MERCURY CONTROL WITH THE ADVANCED HYBRID PARTICULATE COLLECTOR

EXECUTIVE SUMMARY

Since 1995, the U.S. Department of Energy (DOE) National Energy Technology Laboratory (NETL) has supported development of a new concept in particulate control, called the advanced hybrid particulate collector (AHPC). The AHPC has been licensed to W.L. Gore & Associates, Inc., and is now marketed as the Advanced Hybrid™ by Gore. The AHPC combines the best features of electrostatic precipitators (ESPs) and baghouses in a unique configuration, providing major synergism between the two collection methods, both in the particulate collection step and in the transfer of dust to the hopper.

The objective of this project is to demonstrate 90% total mercury control with commercially available sorbents in the AHPC at a lower cost than current mercury control estimates. The approach includes three levels of testing: 1) bench-scale batch testing that ties the new work to previous results and links results with larger-scale pilot testing with real flue gas on a coal-fired combustion system, 2) pilot-scale testing on a previously proven combustion system with both a pulse-jet baghouse and an AHPC to prove or disprove the research hypotheses, and 3) field demonstration pilot-scale testing at a utility power plant to prove scaleup and demonstrate longer-term mercury control.

During the first quarter of the project, initial bench-scale testing was completed, and plans were made for an initial field test earlier than planned in the original schedule.

The bench-scale results were in good agreement with previous data. Results showed that the SO_2 and NO_2 concentration effects are additive and have a significant effect on sorbent performance. This finding should facilitate predicting sorbent performance in real systems when the SO_2 and NO_2 concentrations are known.

Testing with the 2.5-MW AHPC at Big Stone was not scheduled to begin until early 2002 after completing the first pilot-scale tests. However, the project team decided to complete an initial field test the first week of November 2001 prior to the pilot-scale tests at the Energy & Environmental Research Center (EERC).

Results from the initial field test with the Big Stone AHPC showed that:

- The average inlet mercury speciation for seven samples was 55.4% particulate bound, 38.1% oxidized, and 6.4% elemental. The high level of particulate-bound mercury and oxidized mercury was somewhat surprising because for western PRB (Powder River Basin) coals lower levels of particulate-bound mercury and oxidized mercury are more typical. However, significant capture of mercury by the fly ash has been observed in previous EERC pilot tests as well as a number of coal-fired plants burning western fuels. Possible factors that determine the level of particulate-bound and oxidized

mercury include coal type, boiler type, HCl (as well as other flue gases), temperature, and amount of carbon in the fly ash. The current level of understanding of how these factors work together is insufficient to explain the observed mercury speciation for individual plants.

- A carbon injection rate of 1.5 lb/million acf corresponds to a carbon-to-mercury ratio of approximately 2500 for the measured inlet mercury. With this carbon injection rate, from 91% to 97% total mercury collection efficiency was achieved, compared to 49% removal for the baseline case. Even though the carbon addition rate was low, the carbon was highly effective at removing mercury. The data show that the carbon was effective at removing both elemental and oxidized mercury.

- These short-term tests are highly encouraging because they prove that excellent mercury removal can be achieved with very low addition rates of carbon injected upstream of the AHPC. Further testing is needed to demonstrate that the high level of mercury removal can be maintained over the longer term and that the carbon injection will not have any adverse effect on the longer-term operation of the AHPC.

Following the initial field test, additional bench-scale tests as well as the first planned pilot-scale tests were completed. A key finding from the bench-scale tests was that the fixed-bed sorbent-screening tests using simulated flue gas were in good agreement with similar tests sampling real flue gas. This suggests that as long as the main flue gas components are duplicated, the bench-scale fixed-bed tests can be utilized to indicate sorbent performance in larger-scale systems.

In the pilot-scale tests, a baseline comparison was made between the AHPC and a pulse-jet baghouse in terms of the mercury speciation change across the device and the amount of mercury retained by the fly ash. Results showed that for both devices there was very little capture of mercury by the fly ash. There was some increase in oxidized mercury, but no significant differences were noted between the AHPC and pulse-jet modes of operation.

Even though the same coal was used in the pilot-scale tests and the field tests, there was a significant difference in inlet mercury speciation. For the pilot-scale tests, results were more similar to what is typically expected for PRB coals in that most of the mercury was elemental, with little mercury capture by the fly ash. In contrast, for the field test, there was much more oxidized than elemental mercury and significant mercury capture by the fly ash. Possible reasons for the difference include higher carbon in the field ash, somewhat higher HCl in the field flue gas, possible variation in the coal, cyclone firing for the field compared to pulverized coal firing for the pilot tests, longer residence time for the field tests, and a finer particle size for the field test.

During the last quarter (April–June 2002), a number of baseline and carbon injection tests were completed with Belle Ayr PRB subbituminous coal. For the baseline case, approximately 70% of the inlet mercury was elemental, approximately 23% oxidized, and 2% or less was associated with particulate matter. There was very little natural mercury capture across the

AHPC for the baseline tests and only a slight increase in the level of oxidized mercury across the AHPC during baseline operation.

With carbon injection, a comparison of short and long residence time in the AHPC showed that somewhat better mercury removal was achieved with longer residence time. No evidence of desorption of mercury from the carbon was seen upon continued exposure to flue gases up to 24 hours. This suggests that desorption of captured mercury from the carbon sorbent is not a significant problem under these flue gas conditions with the low-sulfur subbituminous coal.

At a carbon-to-mercury ratio of 3000:1, from 50% to 71% total mercury was achieved. When the ratio was increased to 6000:1, the removal increased to the range from 65% to 87%. These results are highly encouraging, because this level of control was achieved for the very difficult case with predominantly elemental mercury and very little natural capture of mercury by the fly ash.

During the power-off batch injection cycles, the mercury removal was well over 90% for the first half of each cycle. This is encouraging because it indicates that over 90% removal is possible with the low-cost flue gas desulfurization sorbent and that with further optimization, 90% control should be achievable, even for a coal that produces mostly elemental mercury and with little natural mercury capture in the fly ash.

A baseline test with an eastern bituminous coal resulted in loss on ignition levels in the fly ash from 10% to 20%. At the 10% carbon level, there was minimal capture of mercury by the fly ash, but at 20% most of the mercury was retained by the fly ash. This suggests that the relationship between the amount of carbon in the ash and the level of mercury capture is complex and may depend more on critical carbon characteristics than on the amount of carbon present.

MERCURY CONTROL WITH THE ADVANCED HYBRID PARTICULATE COLLECTOR

1.0 INTRODUCTION

This project was awarded under U.S. Department of Energy (DOE) National Energy Technology Laboratory (NETL) Program Solicitation DE-PS26-00NT40769 and specifically addresses Technical Topic Area 4 – Testing Novel and Less Mature Control Technologies on Actual Flue Gas at the Pilot Scale. The project team includes the Energy & Environmental Research Center (EERC) as the main contractor; W.L. Gore & Associates, Inc., as a technical and financial partner; and the Big Stone Power Plant operated by Otter Tail Power Company, which is hosting the field testing portion of the research.

Since 1995, DOE has supported development of a new concept in particulate control, called the advanced hybrid particulate collector (AHPC). The AHPC has been licensed to W.L. Gore & Associates, Inc., and is now marketed as the Advanced Hybrid™ by Gore. The AHPC combines the best features of electrostatic precipitators (ESPs) and baghouses in a unique configuration, providing major synergism between the two collection methods, both in the particulate collection step and in the transfer of dust to the hopper. The AHPC provides ultrahigh collection efficiency, overcoming the problem of excessive fine-particle emissions with conventional ESPs, and it solves the problem of reentrainment and re-collection of dust in conventional baghouses. In Phase II of the DOE-funded AHPC project, a 2.5-MW-scale AHPC was designed, constructed, installed, and tested at the Big Stone Power Plant. For Phase III, further testing of an improved version of the 2.5-MW-scale AHPC at the Big Stone Power Plant was conducted to facilitate commercialization of the AHPC technology. The AHPC appears to have unique advantages for mercury control over baghouses or ESPs as an excellent gas–solid contactor.

The objective of this project is to demonstrate 90% total mercury control with commercially available sorbents in the AHPC at a lower cost than current mercury control estimates. The approach includes three levels of testing: 1) bench-scale batch testing that ties the new work to previous results and links results with larger-scale pilot testing with real flue gas on a coal-fired combustion system, 2) pilot-scale testing on a previously proven combustion system with both a pulse-jet baghouse and an AHPC to prove or disprove the research hypotheses, and 3) field demonstration pilot-scale testing at a utility power plant to prove scaleup and demonstrate longer-term mercury control.

2.0 EXPERIMENTAL

2.1 Objective and Goals

The overall project objective is to demonstrate 90% total mercury control with commercially available sorbents in the AHPC at a lower cost than current mercury control estimates.

Test goals include the following:

- Determine if the bench-scale mercury breakthrough results can be duplicated when real flue gas is sampled.
- Compare the level of mercury control with sorbents under similar conditions at the 55-kW pilot scale between the AHPC and a pulse-jet baghouse.
- Demonstrate 90% mercury capture for both a western subbituminous and an eastern bituminous coal.
- Demonstrate mercury capture with the 2.5-MW AHPC at Big Stone.
- Demonstrate 90% mercury capture over a longer time (3 months) with the 2.5-MW AHPC at Big Stone.

2.2 Planned Scope of Work

To meet the objectives, the work was organized into five tasks:

- Task 1: Project Management, Reporting, and Technology Transfer
- Task 2: Bench-Scale Batch Testing
- Task 3: Pilot-Scale Testing
- Task 4: Field Demonstration Pilot Testing
- Task 5: Facility Removal and Disposition

2.2.1 Task 1 – Project Management, Reporting, and Technology Transfer

Task 1 includes all of the project management requirements, including planning, coordination among team members, supervision of tests, review of results, meeting attendance, and all aspects of reporting.

2.2.2 Task 2 – Bench-Scale Batch Testing

The bench-scale tests are for the purpose of verifying previous results, expanding on the SO_2 and NO_2 concentration effect, linking the synthetic gas results to the results with real flue gas, and for screening sorbents.

The 30 tests planned with the bench-scale unit are divided into three series that follow a logical progression. The purpose of the first series of tests is to ensure that results obtained by the EERC and others can be duplicated and, second, to include SO_2 and NO_2 as variables. Series 1 tests, shown in Table 1, are intended to verify the previous bench-scale work and expand on the SO_2 and NO_2 concentration effect. In previous work, no tests were completed in which both the SO_2 and NO_2 were reduced at the same time. In all of these tests, the inlet Hg^0 concentration is typically 15 $\mu g/m^3$ and each test is run for a duration of approximately 4 hr. The 150 mg of Norit Americas FGD activated carbon sorbent is equivalent to a sorbent-to-mercury ratio of 3700 after 3 hr of exposure. This concentration has been shown to provide consistent results in previous testing and is sufficient to accurately measure the amount of mercury in the spent sorbent for mass balance closure. The Series 1 tests were previously completed, and results were reported in the January–March 2002 quarterly report.

The second series of bench-scale tests (Table 2) is for the purpose of comparing the bench-scale fixed-bed results sampling real flue gas to those obtained with simulated flue gas for both a western subbituminous and an eastern bituminous coal. The simulated flue gas concentrations are based on the actual concentrations measured in the combustion tests. In addition, tests with lower sorbent concentrations will also be conducted with flue gases matched to the two coals to assist in selecting the best sorbent concentrations for the pilot-scale tests. The real flue gas tests are part of the first two pilot-scale tests in Task 3, using a slipstream bench-scale system sampling flue gas from the particulate test combustor (PTC).

After the Series 2 tests, the data will be evaluated to determine if the simulated gas tests provide comparable results to the tests with real flue gas, in terms of initial breakthrough capacity and desorption after 100% breakthrough. If the results are comparable, it will provide confidence in proceeding with the pilot-scale mercury capture tests.

Tests 11–14 of the Series 2 tests were previously completed, and results were presented in the January–March quarterly report.

The third series of bench-scale tests (Table 3) is for the purpose of screening alternative sorbents. The iodine-impregnated activated carbon (IAC) sorbent was chosen because of the excellent results seen in some of the previous EERC pilot-scale tests, especially at higher temperatures from 121°–177°C (250°–350°F). The IAC also appears to be better at capturing Hg^0 than the FGD. However, since the IAC is more costly than FGD, it must be effective at lower concentrations than the FGD. The IAC will be evaluated with flue gas concentrations for both a subbituminous and a bituminous coal at two concentration levels and at two temperatures. Four additional screening tests will be conducted on other promising alternative sorbents to be selected based on new information and availability. The results from these tests will be used to prescreen alternative sorbents that have the potential to provide better mercury capture than the FGD. The most promising sorbent would then be further evaluated in pilot-scale testing in Task 3.

Table 1. Bench-Scale Series 1 – SO_2 and NO_2 Concentration

Test No.	Sorbent Type	Temp., °C	Sorbent Concentration, mg	Flue Gas	SO_2, ppm	HCl, ppm	NO, ppm	NO_2, ppm
1	FGD[1]	135	150	Simulated	1600	50	400	20
2	FGD	135	150	Simulated	500	50	400	20
3	FGD	135	150	Simulated	200	50	400	20
4	FGD	135	150	Simulated	1600	50	400	10
5	FGD	135	150	Simulated	500	50	400	10
6	FGD	135	150	Simulated	200	50	400	10
7	FGD	135	150	Simulated	1600	50	400	5
8	FGD	135	150	Simulated	500	50	400	5
9	FGD	135	150	Simulated	200	50	400	5
10	FGD	135	150	Simulated	Repeat test to be selected			

[1] Flue gas desulfurization.

Table 2. Bench-Scale Series 2 – Real Flue Gas Comparison

Test No.	Sorbent Type	Temp., °C	Sorbent Concentration, mg	Flue Gas	SO_2, ppm	HCl, ppm	NO, ppm	NO_2, ppm
11	FGD	135	150	Real	Flue gas from western coal			
12	FGD	135	150	Real	Duplicate test western coal			
13	FGD	135	150	Simulated*	400	4	300	5
14	FGD	135	150	Simulated Duplicate*	400	4	300	5
15	FGD	135	50	Simulated*	400	4	300	5
16	FGD	135	150	Real	Flue gas from eastern coal			
17	FGD	135	150	Real	Duplicate test eastern coal			
18	FGD	135	150	Simulated*	1000	50	400	10
19	FGD	135	150	Simulated Duplicate*	1000	50	400	10
20	FGD	135	50	Simulated*	1000	50	400	10

* Simulated flue gases will be determined from actual flue gas measurements during combustion tests; values shown are estimates.

2.2.3 Task 3 – Pilot-Scale Testing

Six weeks of testing are planned under Task 3. A week of testing includes an 8-hr heatup period on gas and then approximately 100 hr of steady-state operation firing coal. This allows for

Table 3. Bench-Scale Series 3 – Sorbent Type

Test No.	Sorbent Type	Temp., °C	Sorbent Concentration, mg	Flue Gas	SO_2, ppm	HCl, ppm	NO, ppm	NO_2, ppm
21	IAC	135	150	Simulated*	400	4	300	5
22	IAC	135	50	Simulated*	400	4	300	5
23	IAC	135	150	Simulated*	1000	50	400	10
24	IAC	135	50	Simulated*	1000	50	400	10
25	IAC	163	150	Simulated*	400	4	300	5
26	IAC	163	150	Simulated*	1000	50	400	10
27	New No. 1**	135	150	Simulated*	400	4	300	5
28	New No. 2**	135	150	Simulated*	400	4	300	5
29	New No. 3**	135	150	Simulated*	400	4	300	5
30	New No. 4**	135	150	Simulated*	400	4	300	5

* Simulated flue gases will be determined from actual flue gas measurements during combustion tests; values shown are estimates.

** New sorbents would be selected based on background data and availability.

four 24-hr test periods where the PTC is operated around the clock. The planned 6 weeks of tests are shown in Table 4. The first 2 weeks are for the purpose of generating baseline data without carbon injection for a bituminous and a subbituminous coal with both the pulse-jet baghouse and the AHPC. Each test is for a duration of approximately 48 hr. These tests will establish the amount of mercury capture by fly ash and will determine whether the amount of mercury capture is different between the pulse-jet baghouse and the AHPC. It will also establish the inlet and outlet speciated mercury concentrations and whether there is a change in mercury speciation across both devices. A second purpose for these baseline tests is to provide flue gas to support the bench-scale testing with real flue gas under Task 2.

Weeks 3 and 4 are designed to prove the ability of the technology to control mercury at the 90% level with a western subbituminous coal. Week 5 is for the purpose of testing mercury control in the AHPC with an eastern bituminous coal.

Week 6 is for the purpose of testing alternative sorbents in the AHPC. The need for alternate sorbent testing will be somewhat dependent on the results with the FGD sorbent. If 90% mercury capture was already demonstrated with both coals at a low sorbent concentration (for example, less than 3000:1), then there may be no need to further evaluate other sorbents. In this case, Week 6 would be cancelled, and testing with the field AHPC would proceed. However, if results with the FGD sorbent have not met expectations and other sorbents look more promising or if other unanswered questions remain that could be tested in the pilot tests, Week 6 would be completed.

From the pilot-scale test matrix listed in Table 4, the first three weeks of testing with a western subbituminous coal have all been completed (Tests 1-1, 1-2, 3-1, 3-2, 4-1, and 4-2).

Table 4. Task 3 – Pilot-Scale Testing

Week/ Test	Purpose	Coal	Collection Device	Sorbent Type	C:Hg Ratio	Injection Method
1-1	Baseline	WSB[1]	PJBH[2]	None	NA[3]	NA
1-2	Baseline	WSB	AHPC	None	NA	NA
2-1	Baseline	EB[4]	PJBH	None	NA	NA
2-2	Baseline	EB	AHPC	None	NA	NA
3-1	Hg capture, collection device	WSB	PJBH	FGD	3000[5]	Continuous
3-2	Hg capture, collection device	WSB	AHPC	FGD	3000[5]	Continuous
4-1	Hg capture, residence time	WSB	AHPC	FGD	3000[5]	Continuous
4-2	Hg capture, residence time	WSB	AHPC	FGD	3000[5]	Batch
5-1	Hg capture, residence time	EB	AHPC	FGD	3000[5]	Continuous
5-2	Hg capture, residence time	EB	AHPC	FGD	3000[5]	Batch
6-1	Sorbent type and concentration	WSB	AHPC	New No. 1[6]	3000[5]	Continuous[6]
6-2	Sorbent type and concentration	WSB	AHPC	New No. 1[6]	1000[5]	Continuous[6]
6-3	Sorbent type and concentration	WSB	AHPC	New No. 2[6]	3000[5]	Continuous[6]
6-4	Sorbent type and concentration	WSB	AHPC	New No. 2[6]	1000[5]	Continuous[6]

[1] Western subbituminous.
[2] Pulse-jet baghouse.
[3] Not applicable.
[4] Eastern bituminous.
[5] Estimated concentrations; actual concentration will be based on previous testing.
[6] To be selected.

Results from the first week of testing were reported in the January–March quarterly report. Results from Weeks 3 and 4 are presented later in this report. The Week 2 baseline test with a bituminous fuel was also attempted, but a high level of carbon in the ash resulted in most of the mercury being captured, so this test may be repeated at a later time.

2.2.4 Task 4 – Field Demonstration Pilot Testing

Demonstration of mercury control with the AHPC at the 2.5-MW scale at a utility power plant is the next logical step toward proving the commercial validity of this approach. A total of 5 months of field tests was originally planned. The first month was planned for baseline testing without sorbent injection to establish the mercury concentration, speciation, and amount of fly ash capture as well as to compare mercury emissions at the plant stack with the AHPC outlet.

The second month of field tests was planned for the purpose of establishing the sorbent addition rate to achieve 90% mercury control. Following the second month of field testing was a project decision point to determine if an acceptable level of mercury control has been achieved.

If results are acceptable, field testing will continue. Depending on the level of success with the FGD sorbent in the field and the pilot-scale test results with alternative sorbents, the third month was planned for the purpose of evaluating alternative sorbents. If alternative sorbent testing is not necessary, then 3 months of longer-term testing with the FGD sorbent are to be completed. The longer-term operation will establish whether there are any longer-term problems associated with the sorbent injection such as bag-cleaning problems. If alternative sorbents are tested during Month 3, then the longer-term demonstration testing would last only 2 months.

According to the planned work, testing with the 2.5-MW AHPC at Big Stone Power Plant was not scheduled to begin until after completing the first pilot-scale tests. However, the project team decided to conduct an initial field test the first week of November 2001 prior to the pilot-scale tests at the EERC.

The field test at Big Stone was completed the week of November 5–10, 2001, with baseline testing on the first day, followed by carbon injection in both AHPC and pulse-jet operational modes for the remainder of the week. The starting carbon addition rate was set at 24 kg of carbon sorbent/million m^3 of flue gas (1.5 lb of carbon sorbent/million acf), with the plan that it could be increased if necessary to achieve good mercury control. However, over 90% mercury control was seen at this carbon addition rate so no testing was completed at higher carbon concentrations.

The results from the November field test were previously reported in the October–December quarterly report. Additional field testing with the 2.5-MW field AHPC is now planned for the entire month of August through September 6, 2002.

2.2.5 Task 5 – Facility Removal and Disposition

The field AHPC will be dismantled and removed at the end of this project if no further testing is anticipated in support of subsequent work at the Big Stone Power Plant. If further testing were to be completed with the field AHPC at another site (funded by possible subsequent projects), the AHPC components would be moved to that site. If no other AHPC testing is anticipated, the salvageable AHPC components will be returned to the EERC, and the larger steel components will be disposed of as scrap steel. The site will then be restored to its original condition. The Big Stone Power Plant will be responsible for removing the 24-in. ductwork that breeches the plant ductwork, the electrical power lines, air supply lines, and communication lines once the project is complete.

3.0 RESULTS

Three of planned pilot-scale tests were completed from the matrix in Table 4. The first two of these correspond to Weeks 3 and 4 with a western subbituminous coal. The third week of testing corresponds to baseline tests with a bituminous coal ,which is designated as Week 2 in Table 4.

The two western subbituminous coal tests were run with Belle Ayr coal, which is a western subbituminous coal from the Powder River Basin. This is the coal currently being burned at the Big Stone plant and is the expected coal to be burned at Big Stone during the AHPC field tests planned for August 2002. Note that this is a different PRB fuel than was burned at the plant during the last November field test and the Week 1 pilot-scale tests. The EERC combustion run designations for the two weeks with the subbituminous coal are PTC-BA-628 and PTC-BA-629.

3.1 Week 3 – Pilot-Scale Tests (Run PTC-BA-628)

A 550,000-Btu/hr pulverized coal (pc)-fired unit, known as the PTC, was used to generate fly ash. The coal combustion flue gas exiting the PTC was cooled down to a designated temperature of 135°C (275°F) and then was introduced into the AHPC unit. More detailed information on the AHPC configuration was presented in previous work (1). A dry powder disperser system (TSI Model 3410) was installed 30 feet upstream of the AHPC to inject sorbent into the duct, and the injecting nozzle was faced upstream to enhance dispersion in flue gas. Extensive Ontario Hydro sampling was conducted at both the AHPC inlet and outlet to evaluate the effectiveness of the Norit Americas FGD activated carbon sorbent on mercury control in the AHPC system under various operating conditions.

Five tests were completed with the pilot-scale AHPC unit at the EERC to evaluate the effect of corona current and residence time on mercury capture and to compare AHPC with a pulse-jet baghouse. A detailed test matrix is listed in Table 5. The residence time of the injected sorbent in the unit was controlled by the time interval of emptying ash from the hopper. By using the TSI dry powder disperser, the activated carbon was continuously injected into the system at carbon-to-mercury ratios of 3000:1 or 6000:1.

3.1.1 Coal and Combustion Flue Gas Analyses

The proximate and ultimate analysis data for the Belle Ayr coal are in Table 6. The raw coal was also analyzed for mercury content (also listed in Table 6), showing a concentration of mercury in the range of 0.077–0.089 μg/g (dry basis), with a mean value of 0.083 μg/g. Based on the proximate and ultimate analysis data, it was calculated that 1 lb of coal would produce 107.3 scf of dry flue gas normalized to 3.0% oxygen level. From the mercury content in raw coal, the total mercury concentration in flue gas was expected to be 12.4 $\mu g/m^3$ of dry flue gas (at 3% oxygen level).

Table 5. Pilot-Scale Testing Plan for Run PTC-BA-628

Test No.	Operating Mode	Residence Time	C:Hg Ratio	Injection Method
1	AHPC, 4.0 mA	60 min	None	NA
2	AHPC, 4.0 mA	60 min	3000:1	Continuous
3	Pulse Jet Baghouse	60 min	3000:1	Continuous
4	AHPC, 0.5 mA	60 min	3000:1	Continuous
5	AHPC, 4.0 mA	24 hr	6000:1	Continuous

Table 6. Coal Analysis for Run PTC-BA-628

Proximate Analysis, %	As Sampled	Moisture Free
Moisture Content	24.8	NA
Volatile Matter	35.94	47.83
Fixed Carbon	34.42	45.74
Ash	4.83	6.43
Ultimate Analysis, %		
Hydrogen	6.29	4.69
Carbon	51.42	68.42
Nitrogen	0.8	1.07
Sulfur	0.29	0.38
Oxygen	36.37	19.01
Ash	4.83	6.43
Heating Value, Btu/lb	8999	11975
Mercury Concentration in Coal, μg/g		
Sample 1		0.077
Sample 2		0.089
Mean		0.083

Table 7. Summary of the Flue Gas Compositions During the Run PTC-BA-628 (dry basis)

		O_2, %	CO_2, %	CO, ppm	NO, ppm	NO_2, ppm	SO_2, ppm	HCl, ppm
Day 1	In	4.8	14.3	3.9	590	–	314	–
	Out	5.13	13.5	-–	537	–	307	–
Day 2	In	4.5	14.3	4.5	559	4	306	2.7
	Out	5.2	–	–	540	3	266	–
Day 3	In	4.6	14.8	3.6	558	–	316	3.7
	Out	5.9			533	–	289	–
Day 4	In	4.6	14.2	3.4	571	–	312	3
	Out	4.8	–	–	547	–	289	–
Day 5	In	4.4	14.9	3.51	580	5	331	–
	Out	5.1	–	–	571	7	291	–

The flue gas compositions, O_2, CO_2, CO, NO, NO_2, SO_2, both at the AHPC inlet and outlet, were monitored during the testing period, and the daily average values were calculated and listed in Table 7. The CO concentration was in the range of 3–5 ppm, indicating complete coal combustion. The low-sulfur Belle Ayr coal produced SO_2 in the flue gas ranging from 306 to 331 ppm. The NO and NO_2 concentrations in the flue gas were 571–590 ppm for NO and only 4–7 ppm for NO_2. The O_2 concentration was slightly increased from the inlet to the outlet because of the air leakage in the system. Three U.S. Environmental Protection Agency (EPA) Method 26 samples were collected at the AHPC inlet for chlorine concentration in flue gas. The analysis results are also shown in Table 7. Because of the low levels of CO, SO_2, NO, NO_2, and HCl in flue gas, most mercury in the flue gas was expected to be elemental vapor phase.

3.1.2 Mercury Results for Run PTC-BA-628

Ontario Hydro sampling trains were set up at the AHPC inlet and outlet to measure mercury species in the flue gas. The sampling time was typically 2 hr. The flue gas was isokinetically sampled and filtered. The particle-free flue gas then passed through a series of impingers to capture oxidized and elemental mercury followed by a silica gel-filled impinger to remove remaining moisture. Ontario Hydro sampling results provide mercury species information in flue gas as elemental mercury vapor, oxidized mercury vapor, and mercury associated with particulate. All results are presented in the form of $\mu g/Nm^3$ based on the cold vapor atomic absorption (CVAA) analysis results of the impinger solutions, sampling flue gas volume, and dust loading. All the measured mercury concentrations in the flue gas were corrected to the concentrations under a flue gas condition of a moisture-free 3% O_2 level.

Because this was a different coal than was evaluated in the Week 1 baseline test (see Table 4), Test 1 from this run was designated as a baseline. In Test 1, the system was operated in AHPC mode with a corona current of 4.0 mA. The collection plates and electrodes were rapped every 60 min followed by a pulse-jet bag cleaning. The hopper ash was then emptied to maintain the residence time of the fly ash in the chamber at approximately 60 min. No activated carbon was injected into the system during the testing period, and a total of three pairs of Ontario Hydro samples were carried out at both the AHPC inlet and outlet. The purpose of Test 1 was to establish the inlet and outlet species mercury concentrations and determine whether there was a change in mercury speciation across the AHPC unit. The results are shown in Figure 1. At the AHPC inlet, oxidized mercury vapor varied from 1.18 to 3.69 $\mu g/m^3$, while the elemental mercury vapor was dominant, in the range of 4.93–7.88 $\mu g/m^3$. Mercury associated with particulate was at a very low level, ranging from 0.09–0.17 $\mu g/m^3$, showing little capture of mercury by fly ash particles. The total mercury concentration in flue gas (presented as total mercury concentration at the AHPC inlet) varied from 8.83 to 9.24 $\mu g/m^3$, somewhat lower than the theoretical value of 12.4 $\mu g/m^3$ obtained from the coal combustion calculation based on the coal analysis. The slight difference may be the result of uncertainty in the mercury analysis as well as additional process variability. Because of the excellent fly ash capture efficiency of the AHPC, particulate associated mercury was completely removed from the flue gas. The total mercury in the flue gas at the outlet (also shown in Figure 1) was about the same as the AHPC inlet, showing virtually no capture of mercury vapor (including both elemental and oxidized mercury vapor) across the AHPC.

To better clarify the transformation of mercury species across the AHPC unit, the average normalized mercury species distribution at the AHPC inlet is shown in Figure 2. At the AHPC inlet, 75.5% of mercury was in elemental state, 22.9% was oxidized mercury vapor, and only 1.6% of total mercury was associated with fly ash particles. Because of the excellent capture of fly ash by the AHPC, the mercury associated with fly ash was all collected in the hopper. The mercury in the hopper ash was analyzed, added to the outlet mercury species, and normalized to 100% for comparison with the inlet. The results show a slight increase in oxidized mercury from 22.9% to 28.8% across the AHPC unit while there was a corresponding decrease in elemental mercury from 75.5% at the inlet to 71.7% at the outlet.

During Tests 2 and 3, the FGD activated carbon was continuously injected into the flue gas prior to the AHPC at a rate of 6.62 g/hr, corresponding to a carbon-to-mercury ratio of 3000:1. The unit was either operated in AHPC mode (Test 2) with a 4.0-mA corona current or in pulse-jet baghouse mode (Test 3) with a pulse trigger pressure of 8.0 in. W.C. The residence time of the fly ash as well as the activated carbon in the unit was limited to 1 hr. For Test 2, the total mercury concentration at the AHPC inlet, according to mercury species measurement shown in Figure 3, was in the range of 8.44–9.16 $\mu g/m^3$: 73.2% of elemental mercury; 23.1% of oxidized mercury, and 3.6% of mercury associated with particulate. In the presence of the activated carbon in the flue gas, the outlet mercury emission was reduced to 0 $\mu g/m^3$ of particulate mercury, 1.53–1.86 $\mu g/m^3$ of elemental mercury vapor, and 2.57–2.87 $\mu g/m^3$ of oxidized mercury. Most of the elemental mercury vapor was either directly adsorbed on the activated carbon or oxidized followed by absorption on the activated carbon particles. Again, mercury associated with particulate was completely removed from the flue gas because of the excellent filtration efficiency. The overall mercury collection efficiency of 48.4% compared to virtually no capture of mercury without carbon indicates the carbon injection was effective to some degree. However, efficiency was lower than expected based on the bench-scale results, likely because some of the activated carbon was captured on the outside walls rather than the perforated plates or the filtration bags.

Because the small AHPC unit has only one row of bags, some of the dust is collected on the outside walls of the AHPC housing. Dust deposited on the outside walls is taken out of the flow stream compared to the dust collected on the perforated plates or bags. To help minimize this effect, some later tests were completed with a reduced corona current. The lower current was still high enough for good operation, but could improve the gas–sorbent contact.

In Test 3, the unit was operated in a baghouse mode (without high-voltage power). The high air-to-cloth (A/C) ratio of 12 ft/min resulted in a frequent bag pulse cleaning every 5–7 min caused by the high dust loading to the filter bags and severe fly ash reentrainment. The measured mercury species concentrations at the AHPC inlet and outlet are shown in Figure 4. The mercury species concentrations at the AHPC inlet during this test were somewhat different from the previous tests in that more mercury vapor was already in oxidized state at the AHPC inlet: 1.82–4.7 $\mu g/m^3$ of Hg^0, 1.65–5.03 $\mu g/m^3$ of Hg^+, and 0.76–1.09 $\mu g/m^3$ of Hg(p). The total outlet mercury concentration was reduced to 2–2.17 $\mu g/m^3$ at the 3000:1 carbon-to-mercury ratio, a total mercury collection efficiency of 72.7%. Compared to the 48.4% mercury capture in AHPC mode, the baghouse mode appeared to provide a higher collection efficiency with the same

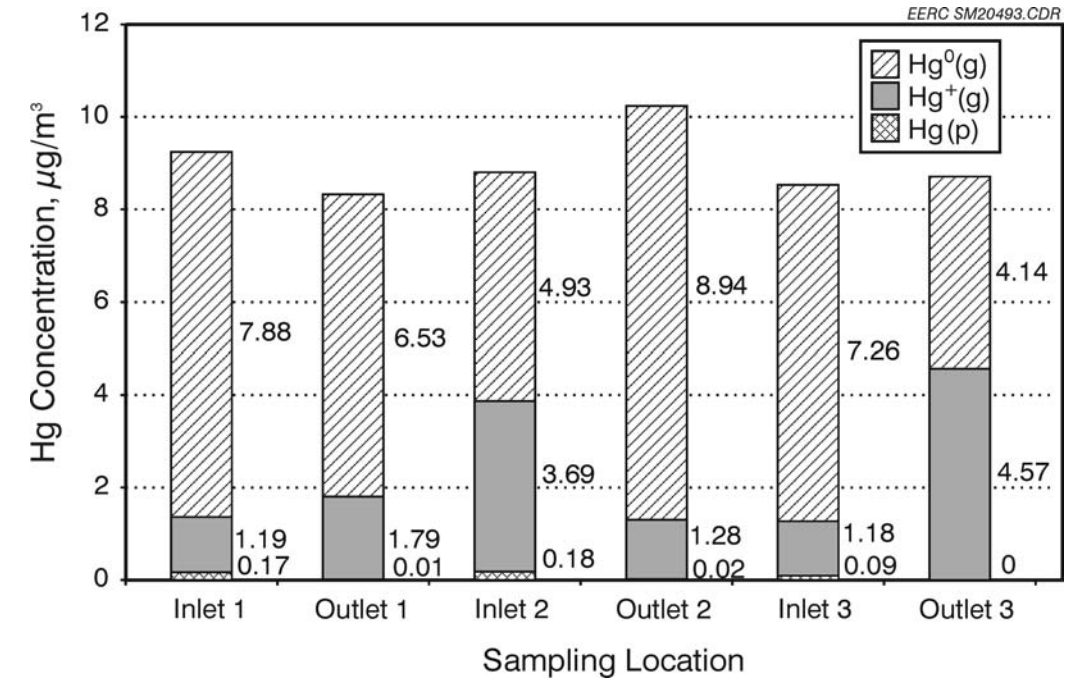

Figure 1. Test 1 – baseline, mercury species concentration in flue gas at the AHPC inlet and outlet (AHPC mode, 4.0 mA, 60-min residence time).

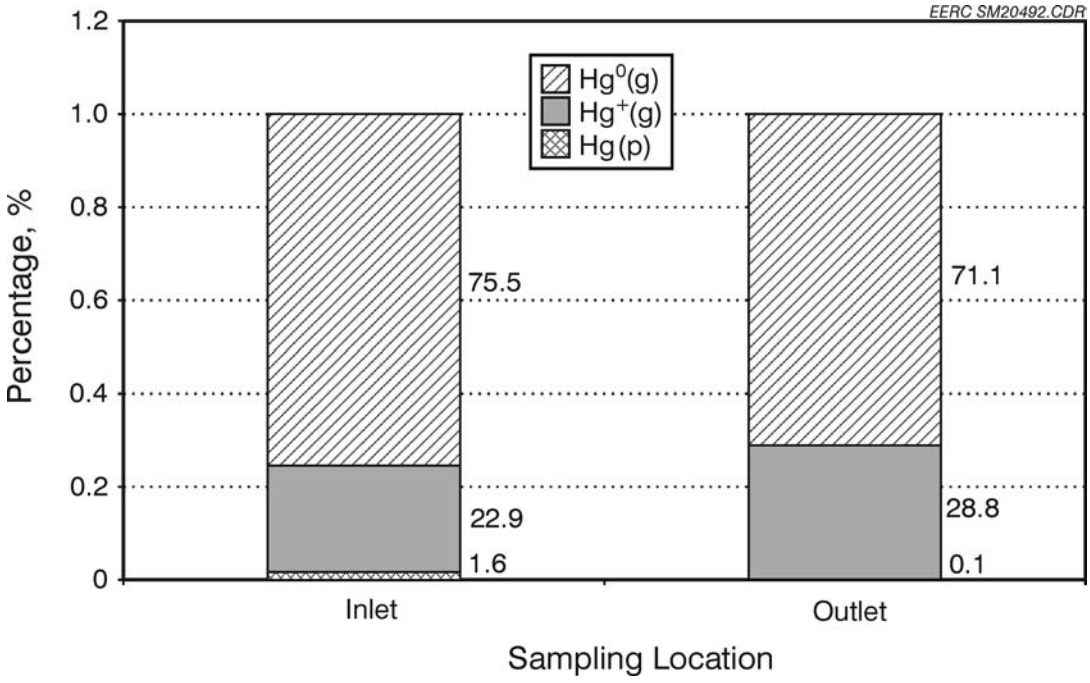

Figure 2. Test 1 – baseline, normalized mercury species distribution in flue gas across the AHPC unit (AHPC mode, 4.0 mA, 60-min residence time).

carbon-to-mercury ratio. However, for the pulse-jet test the inlet mercury was much higher in oxidized mercury and also had more particulate mercury. Since the oxidized mercury is typically easier to capture, the comparison is not valid. Along with the previous results from the November test at Big Stone and the later tests for this run, the general conclusion is that for these conditions both the pulse-jet mode and AHPC mode can produce good mercury control with a low addition rate of the FGD sorbent.

In Test 4, the system was back to AHPC mode with a reduced corona current of 0.5 mA, while the carbon-to-mercury ratio and residence time of the sorbent were the same as before. Under these conditions, more activated carbon was expected to collect on the perforated plates and on the bag surface, which, in turn, should enhance the mercury absorption. One pair of Ontario Hydro samples was carried out at the inlet and outlet, and the results are shown in Figure 5. The total mercury concentration at the inlet was 7.55 $\mu g/m^3$: 2.58 $\mu g/m^3$ of elemental mercury, 4.11 $\mu g/m^3$ of oxidized mercury, and 1.06 $\mu g/m^3$ of particulate mercury. The outlet total mercury emission was reduced to 3.46 $\mu g/m^3$, resulting in an increased overall mercury collection efficiency of 54.2% compared to the 48.4% obtained in Test 2. The reduced corona current appeared to somewhat improve mercury capture, but there was still considerable capture of dust on the outside walls.

In order to achieve a higher mercury capture, the carbon injection rate was doubled in Test 5, corresponding to a carbon-to-mercury ratio of 6000:1. The unit was in AHPC mode with a 0.5-mA corona current. The residence time of the sorbent in the AHPC chamber was extended to 24 hr. The Ontario Hydro sampling results are shown in Figure 6. Again, all the particulate mercury was removed from flue gas because of the excellent particle collection efficiency. Most of the elemental mercury vapor (>80%) at the AHPC inlet was removed from the flue gas either by direct absorption on the activated carbons or oxidation followed by absorption. The elemental mercury vapor at the outlet was in the range of 0.6–0.97 $\mu g/m^3$, while the oxidized mercury was 0.83–1.76 $\mu g/m^3$. Early in the test the first pair of Ontario Hydro samples indicated 68% removal, but the second pair of samples near the end of the test indicated 83% removal, possibly because of the extended residence time in the chamber. However, concern is that if the exposure time is too long the sorbent may desorb mercury. The bench-scale results indicate this will mostly likely occur in cases with very high SO_2 and NO_2 concentrations. Even though the sorbent particles were kept in the AHPC chamber for 24 hr, no obvious desorption of mercury from the sorbent was observed. These results are highly encouraging because they are for the difficult scenario with mostly elemental mercury and no inlet particulate mercury.

A summary of AHPC mercury collection efficiency under the different operating conditions is shown in Figure 7. Without carbon injection, the Belle Ayr coal shows virtually no capture of mercury. Under the 3000:1 carbon-to-mercury injection ratio, the overall mercury collection efficiency in AHPC operating mode ranged from 48.4% to 54.2%, depending on the corona current. When the carbon-to-mercury ratio increased from 3000:1 to 6000:1 under AHPC mode with the same 0.5-mA corona current and with extended residence time, the mercury capture efficiency was increased to 83%. The excellent mercury removal for the last test was also confirmed by continuous emission monitors (CEMs). Inlet and outlet mercury monitor data

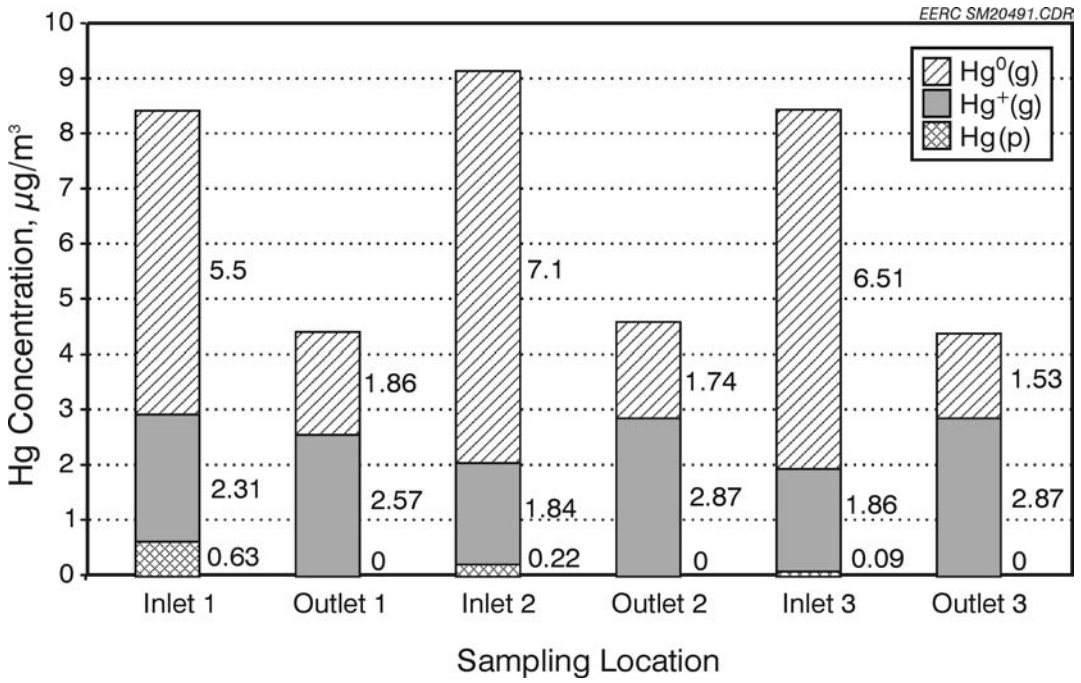

Figure 3. Test 2 – mercury species concentration in flue gas at the AHPC inlet and outlet (AHPC mode, 4.0 mA, 60-min residence time, 3000:1 carbon injection ratio).

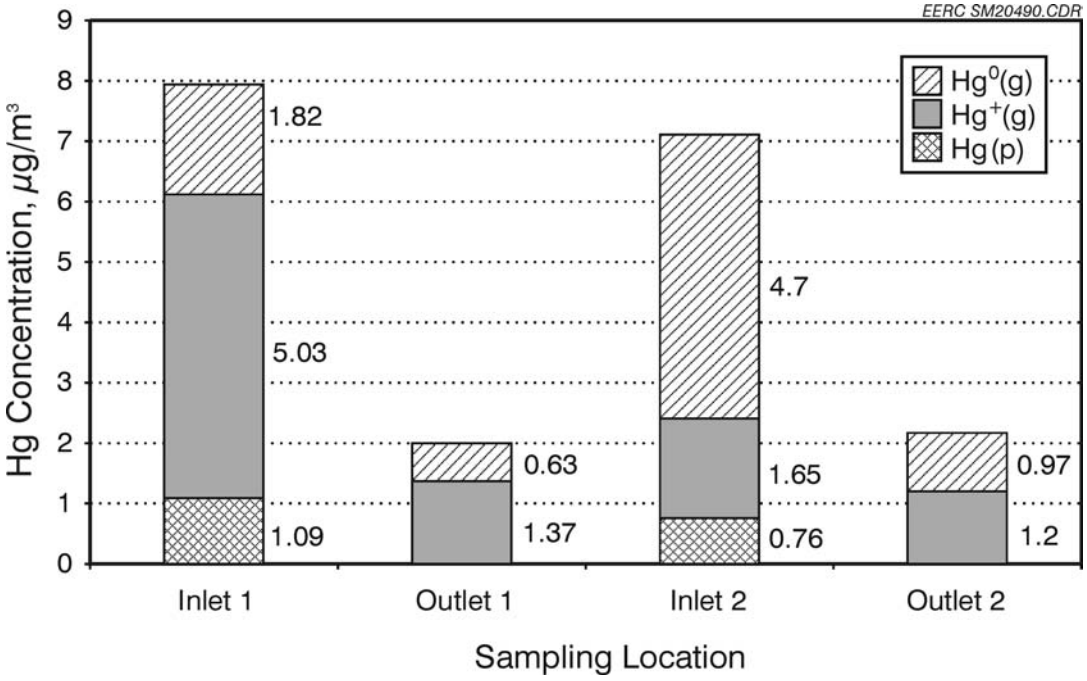

Figure 4. Test 3 – mercury species concentration in flue gas at the AHPC inlet and outlet (baghouse mode, 8.0-in. W.C. pulse trigger pressure, 60-min residence time, 3000:1 carbon injection ratio).

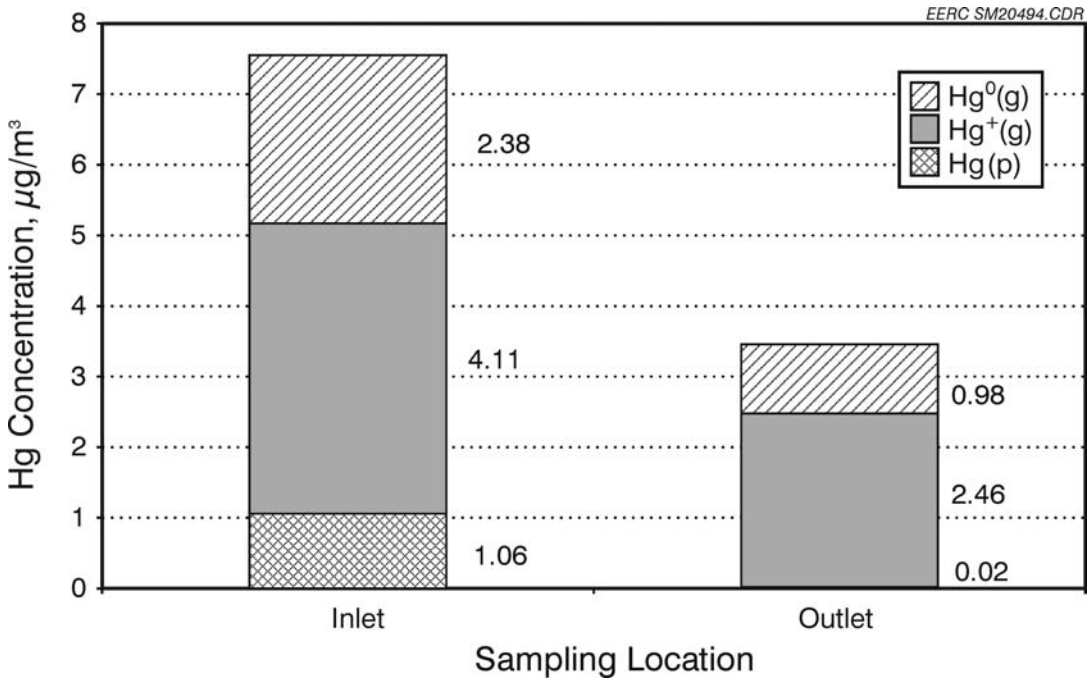

Figure 5. Test 4 – mercury species concentration in flue gas at the AHPC inlet and outlet (AHPC mode, 0.5 mA, 60-min residence time, 3000:1 carbon injection ratio).

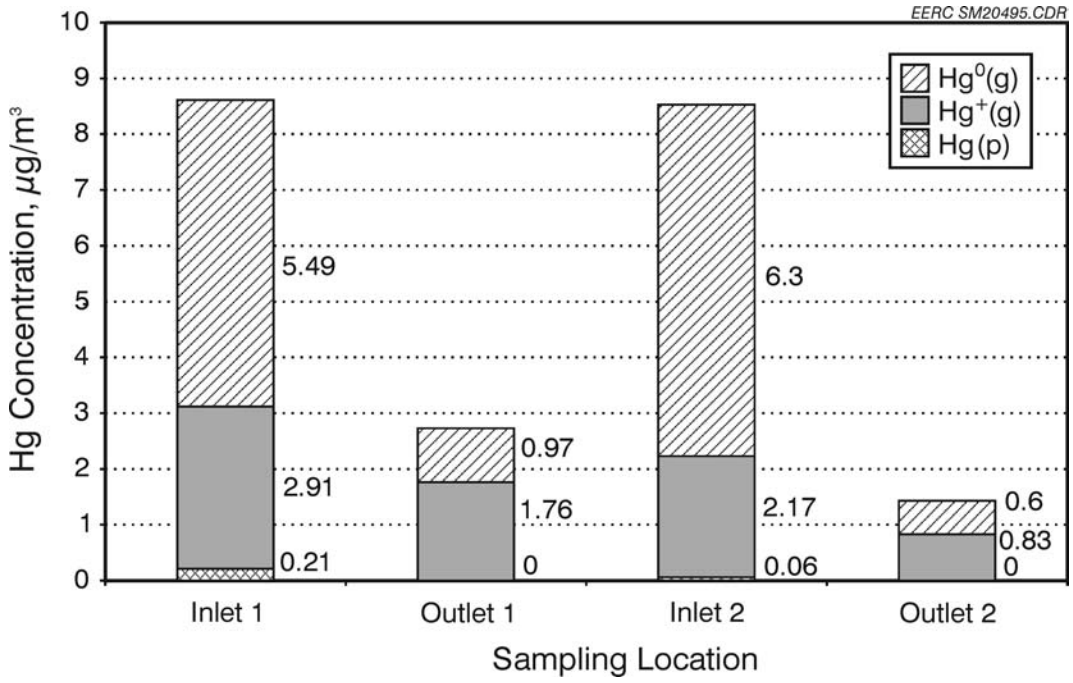

Figure 6. Test 5 – mercury species concentration in flue gas at the AHPC inlet and outlet (AHPC mode, 0.5 mA, 24-hour residence time, 6000:1 carbon injection ratio).

are shown in Figure 8 along with the last Ontario Hydro sample. Over an extended period, the mercury monitors indicate about 8.5 μg/m^3 at the inlet and about 1.5 μg/m^3 at the outlet, or about 82% removal efficiency.

3.1.3 Particulate Collection Efficiency for Run PTA-BA-628

While the focus of these tests is mercury control, the Ontario Hydro samples also provide the particulate collection efficiency as shown in Table 8. The data indicate the particulate collection efficiency to be consistently above the goal of 99.99%. In pulse-jet mode, there is clearly some loss in collection efficiency due to no precollection of dust, no enhanced bag cleaning, and much more frequent pulsing than in AHPC mode. Even though the bags were the same for all of the tests, the much higher collection efficiency for the AHPC shows the benefit of the AHPC for reduced fine-particle emissions.

3.2 Week 4 – Pilot-Scale Tests (Run PTC-BA 629)

The purpose of this week of testing was to further expand on the AHPC mercury control tests from the previous tests with the same Belle Ayr subbituminous coal. The primary variable evaluated was the carbon injection approach. When injecting carbon in batch mode, where an amount of carbon is injected every few hours, the longer exposure time of the sorbent to the flue gas may provide better mercury removal than continuous injection. Seven tests were completed, including an initial baseline test without carbon injection, three continuous injection tests, and three batch injection tests (see Table 9). Average flue gas composition for the tests is given in Table 10.

Table 8. PTC-BA-628 – Dust Loading at the AHPC Inlet and Outlet and the Calculated Collection Efficiency

	Inlet, gr/dscf	Outlet, gr/dscf	Collection Efficiency, %
Day 1-1	1.354	0.0002	99.985
Day 1-2	1.43	0.000007	99.999
Day 2-1	1.316	0.0001	99.992
Day 2-2	1.516	0.000007	99.999
Day 2-2	1.59	0.000017	99.998
Day 3-1	1.24	0	100
Day 3-2 (pulse jet)	1.477	0.0008	99.945
Day 3-3 (pulse jet)	1.455	0.0008	99.945
Day 4-1	1.497	0.00003	99.998
Day 4-2	1.483	0.0001	99.993
Day 4-3	1.443	0	100
Day 5-1	1.473	0.00002	99.999

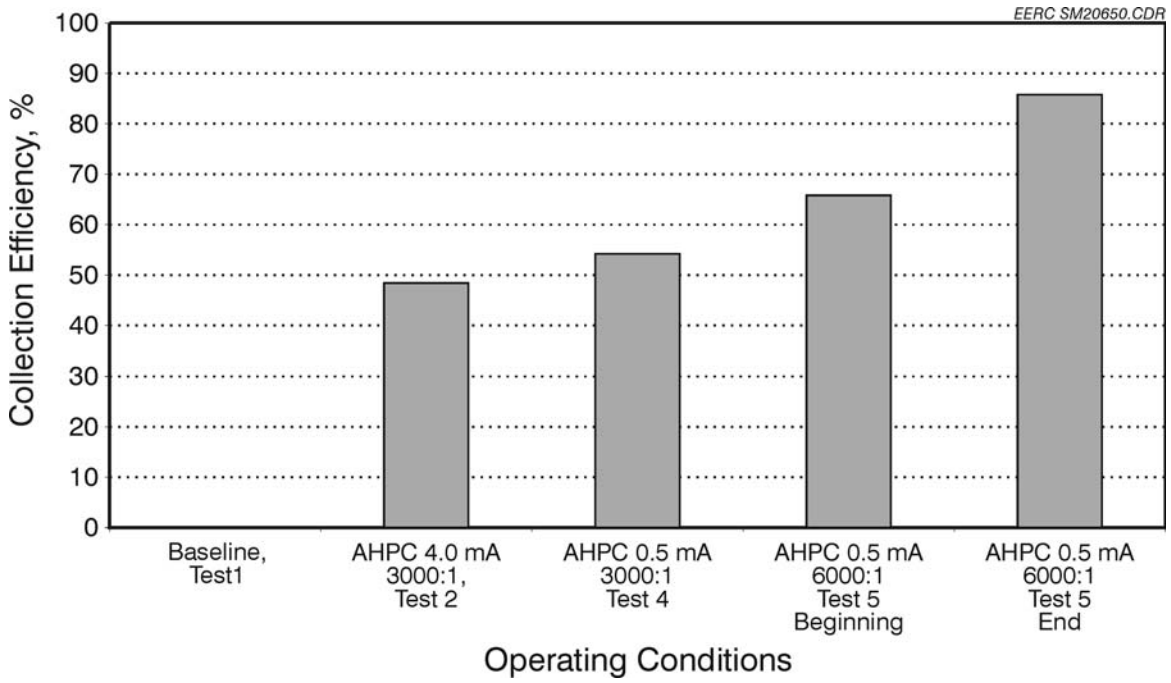

Figure 7. Overall mercury collection efficiency by AHPC under different operating conditions for Run PTC-BA-628.

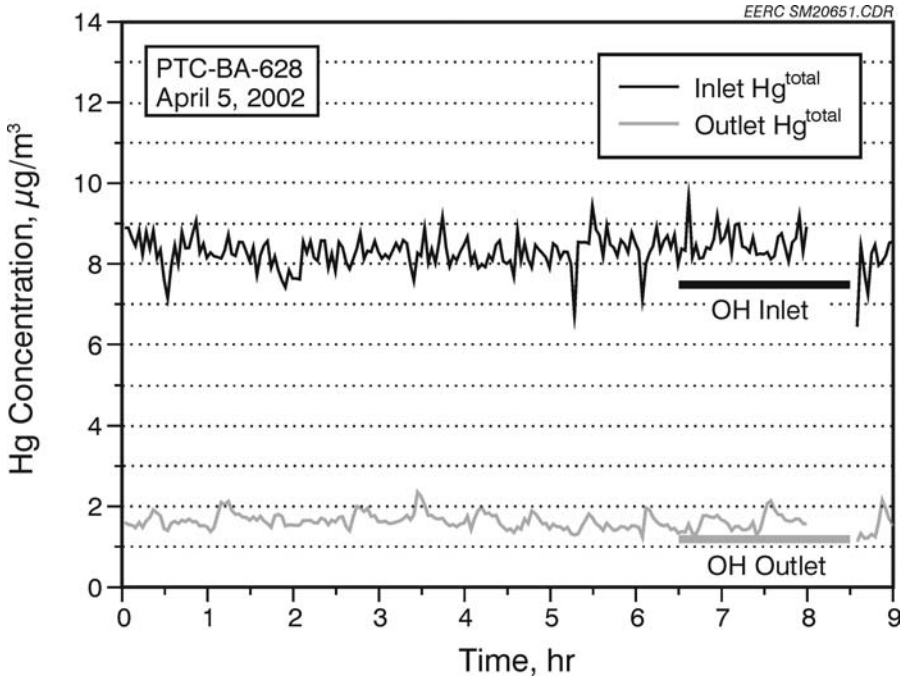

Figure 8. CEM data for PTC-BA-628.

Table 9. PTC-BA-629 – Summary of the Test Scenarios

Test No.	AHPC Current	Carbon: Hg Ratio	Injection Mode
1	4 mA	None	
2	0.5 mA	6000:1	Continuous
3	3.0 mA	6000:1	Continuous
4	3.0 mA	3000:1	Batch power off
5	3.0 mA	6000:1	Batch power off
6	3.0 mA	6000:1	Batch power on
7	3.0 mA	3000:1	Continuous

Table 10. PTC-BA-629 – Summary of the Flue Gas Compositions During the Pilot-Scale Test (dry basis)

	O_2, %	CO_2, %	CO, ppm	NO, ppm	NO_2, ppm	SO_2, ppm	HCl, ppm
Average Inlet	4.5	14.9	4.4	637	8.5	310	2.05

In addition to the Ontario Hydro data, extensive sampling was completed with two mercury monitors, which allowed tracking the mercury concentrations in near-real time. This was especially useful for the batch injection tests, because initially upon injection the mercury quickly dropped to its lowest level and then gradually increased with time.

The Ontario Hydro inlet mercury analyses are shown in Figure 9 along with the average of the six tests. For all but of one of the seven tests, a single pair of inlet and outlet Ontario Hydro samples was taken, but for Test 5, which was shorter in duration, only an outlet mercury sample was taken. From Figure 9 it can be seen that there was consistently very little particulate mercury, averaging only 0.2 $\mu g/m^3$, while the average oxidized mercury was 2.8 $\mu g/m^3$ and the average elemental mercury was 6.9 $\mu g/m^3$ for a total average inlet mercury concentration of 9.9 $\mu g/m^3$. Since only one inlet was completed for each test, the calculated mercury removals were based on the average inlet mercury concentration from all six inlet measurements.

3.2.1 Test 1 – Baseline

The Ontario Hydro mercury results for Test 1 are shown in Figure 10, and the mercury monitor data for Test 1 are given in Figure 11. The Ontario Hydro data from Figure 10 indicate 21% mercury removal, but if the average inlet value is used, the removal is only 10.6%. The mercury monitor data indicate no removal, which is consistent with baseline results from the previous run (PTC-BA-628) and agrees with the very low inlet particulate mercury measured by the Ontario Hydro method.

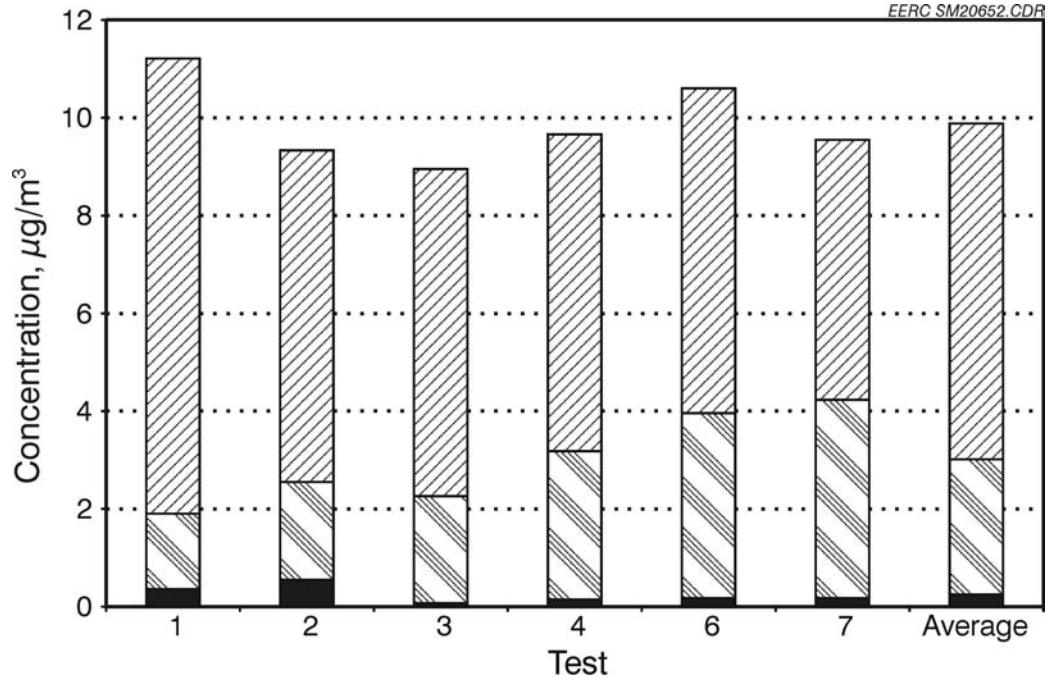

Figure 9. Mercury species concentration at the AHPC inlet for Run PTC-BA-629.

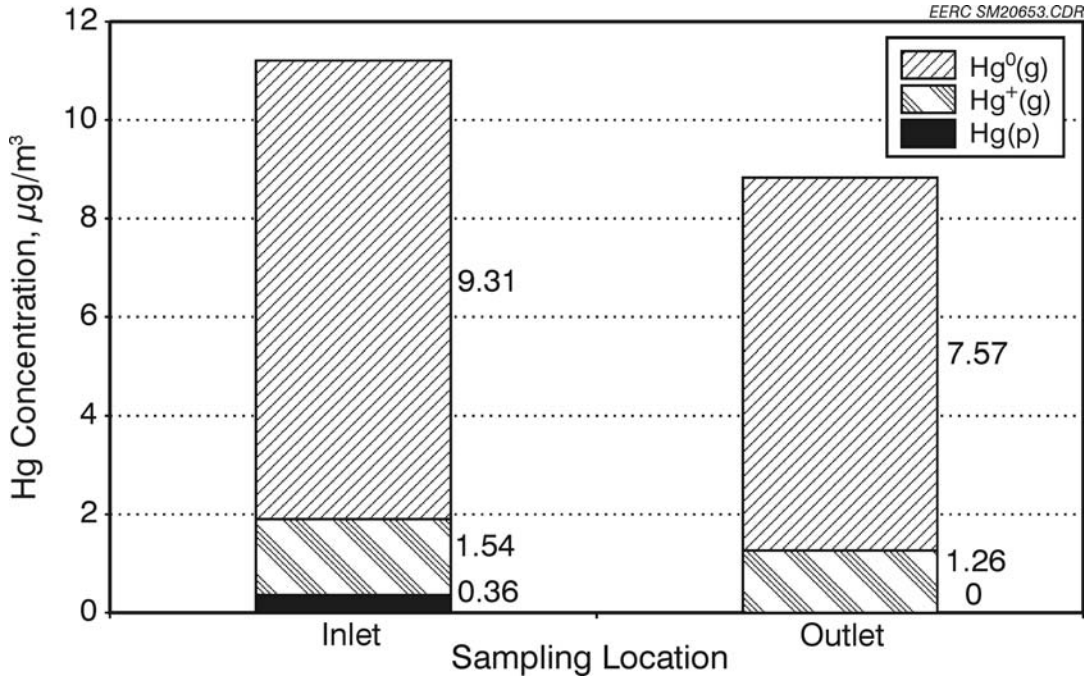

Figure 10. PTC-BA-629 – Test 1 (baseline) – mercury species concentration in flue gas at the AHPC inlet and outlet (AHPC mode, 4.0 mA, 120-min residence time).

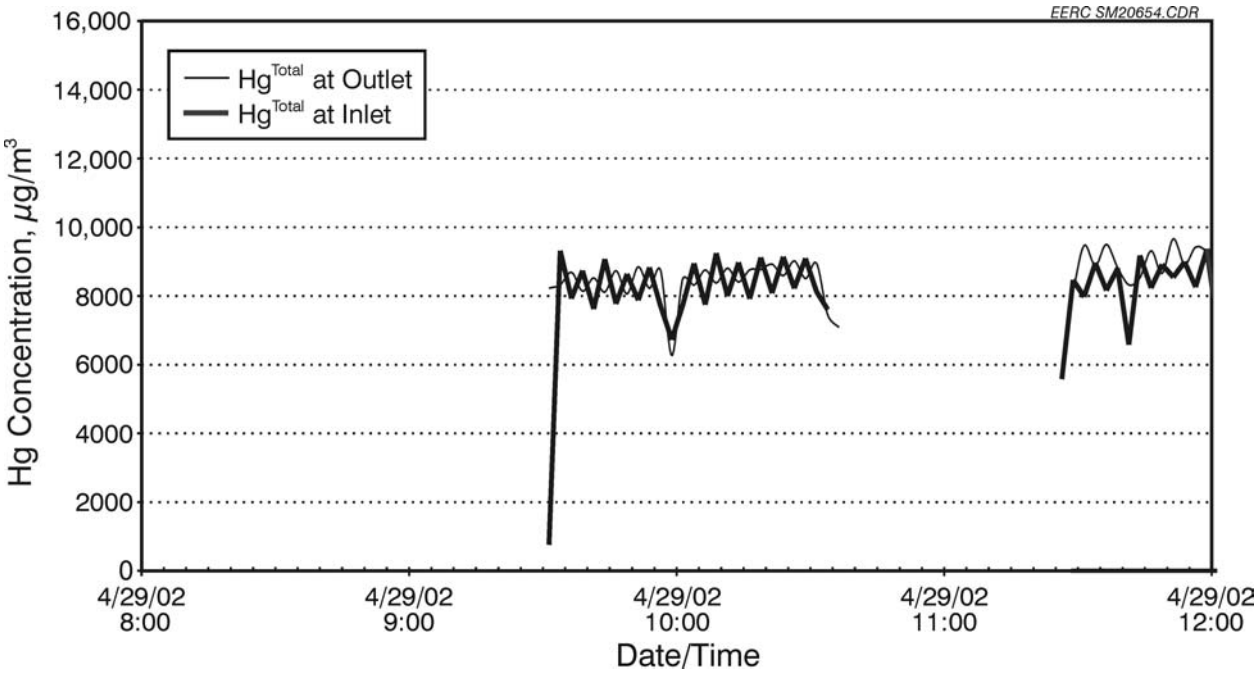

Figure 11. PTC-BA-629 – Test 1 – mercury monitor data.

3.2.2 Test 2 – Continuous Injection at 6000:1 and 0.5-mA Current

Since excellent mercury capture was achieved in the previous run with these conditions, they were selected for the first test. Ontario Hydro and mercury monitor data for Test 2 are given in Figures 12 and 13. The Ontario Hydro average inlet value and the outlet from Test 2 indicate 76.3% removal, while the mercury monitor data near the end of the test suggest about 70% removal, which is in reasonable agreement.

3.2.3 Test 3 – Continuous Injection at 6000:1 and 3-mA Current

The AHPC current was increased from 0.5 to 3 mA to see if the mercury removal would decrease significantly. Results shown in Figures 14 and 15 indicate a slight increase in mercury emissions at the higher current setting. From the Ontario Hydro data, the removal decreased only from 76.3% to 71.5%, while the mercury monitor data also indicate only a small decrease in performance. Since the AHPC operation in terms of pulse interval and pressure drop control is better at the higher current, subsequent tests were completed at the higher current setting.

3.2.4 Test 4 – Batch Injection with Power Off at 3000:1

A total of 13.3 g of the Darco FGD activated carbon was injected at a time interval of every 2 hours which corresponds to an average carbon:mercury ratio of 3000:1. During the batch injection, the AHPC power was momentarily shut off to facilitate the carbon reaching the bags. The combination of power off and added carbon resulted in an immediate increase in pressure drop of about 2 in. W.C. (1 kPa).

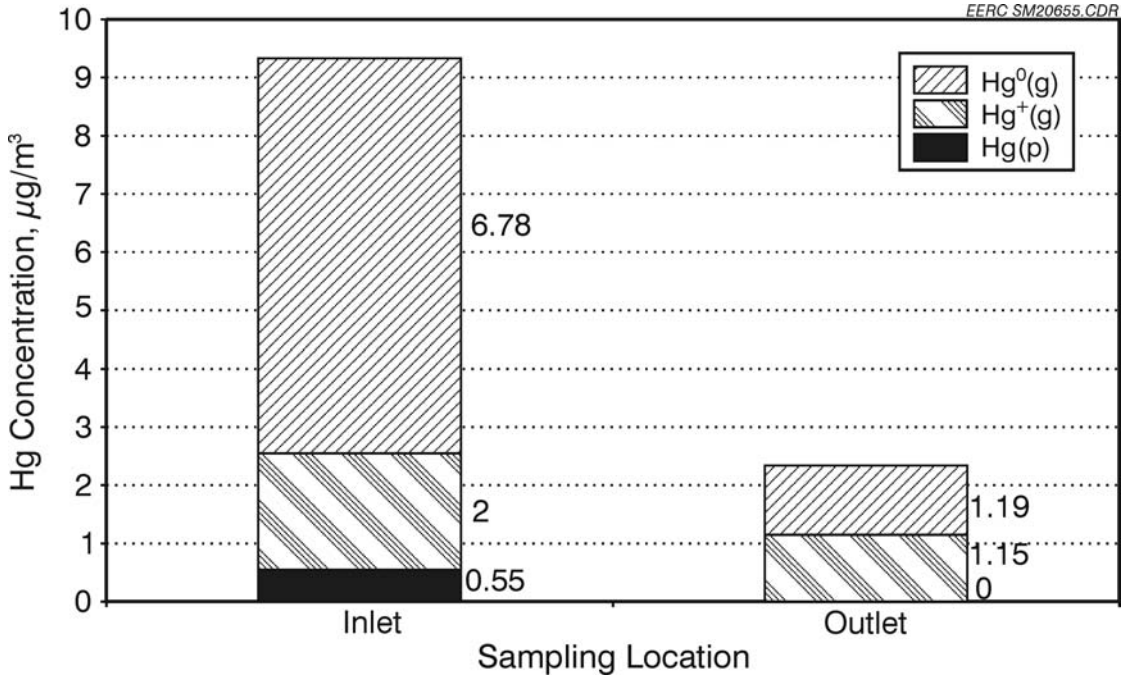

Figure 12. PTC-BA-629 – Test 2 – mercury species concentration in flue gas at the AHPC inlet and outlet (AHPC mode, 0.5 mA, 120-min residence time, 6000:1 carbon injection ratio).

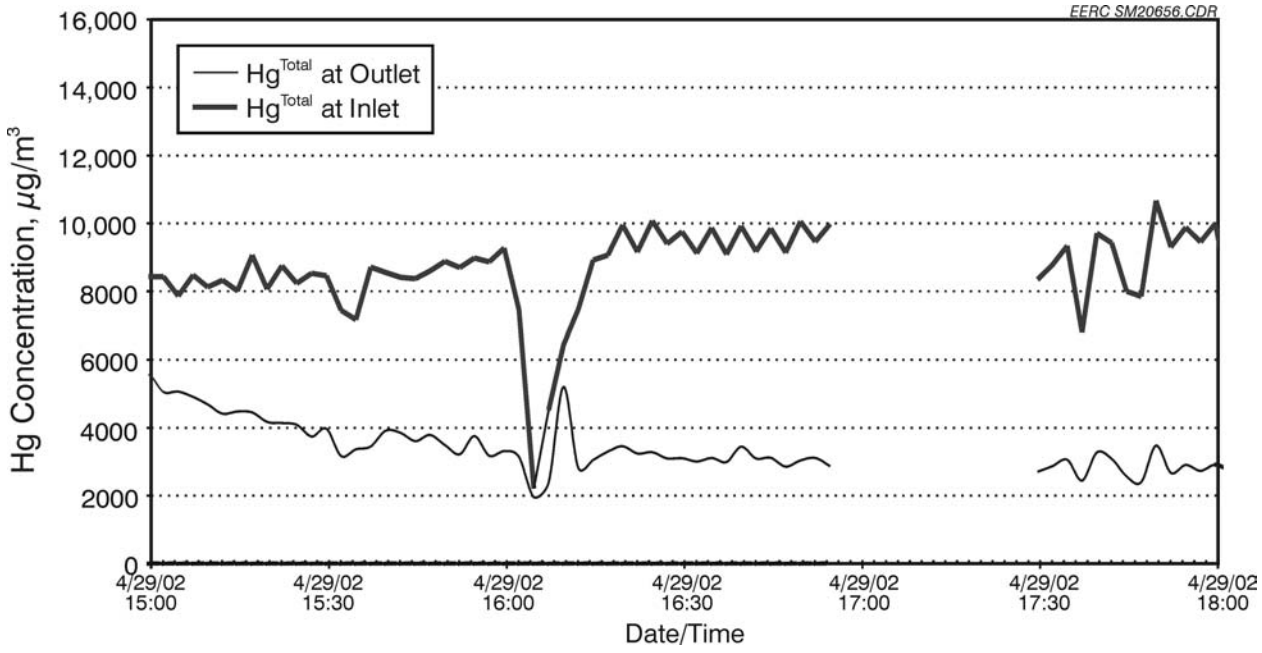

Figure 13. PTC-BA-629 – Test 2 – mercury monitor data.

The outlet Ontario Hydro sample (Figure 16) was taken over a single 2-hour cycle and should represent the total average removal. However, the mercury monitor data (Figure 17) provide more detailed information. Within a few minutes of the injection, the outlet mercury level dropped to near zero for approximately 30 minutes. During this time, the total mercury was well above 90%. However, after this time, the level slowly increased until at the end of 2 hours it was close to the inlet level. The Ontario Hydro data indicate an average of 71.2% removal during this time. This represents an improvement over the level of removal previously seen at 3000:1, but is still lower than the goal of 90% removal.

3.2.5 Test 5 – Batch Injection with Power Off at 6000:1

For Test 5, the amount of carbon injected every 2 hours was increased to 26.6 g. The Ontario Hydro data (Figure 18) indicate the removal improved to 86.8%, very close to the 90% removal goal. The mercury monitor data (Figure 19) also show that the time of over 90% removal increased to about 1 hour after injection and that by the end of the 2-hour interval, the mercury level reached only about 50% of the inlet level.

3.2.6 Test 6 – Batch Injection with Power On at 6000:1

The previous two tests clearly showed that improved mercury capture can be achieved with power-off batch injection, but that approach may not be as practical as batch injection while maintaining the AHPC power. Test 6 was similar to Test 5 except the power remained on during the injection. The calculated removal efficiency from the Ontario Hydro data (Figure 20) was reduced to 75.5%, but was still somewhat better than the 71.5% removal seen with continuous injection in Test 3 under otherwise similar conditions. The mercury monitor data (Figure 21) over multiple injection cycles indicate some differences compared to the power-off batch injection test. After each injection, the mercury level did not drop as low as in the previous test and it started to increase immediately, in contrast to the extended time with batch injection with over 90% removal. This suggests that the carbon was not as well exposed to the flue gas as with the power-off batch injection. From inspection through sight ports of the flow patterns and dust deposits in the AHPC, a significant fraction of the dust is deposited on the outside walls away from the main gas flow region. Altering the inlet configuration to force the gas flow between the discharge electrodes and perforated plates would likely improve the carbon flue gas contact.

3.2.7 Test 7 – Continuous Injection at 3000:1

Another test was completed with continuous injection at the lower carbon injection rate to verify the previous results and to determine if extended operational time might result in a gradual increase in mercury removal as a result of carbon buildup in the system. The Ontario Hydro results (Figure 22) indicate only a 41.7% removal, which is somewhat lower than the results from the previous run (PTC-BA-628) with these conditions. However, the mercury monitor data (Figure 23) indicate about 60% removal over an extended time and show the very steady level of control that is maintained with continuous injection.

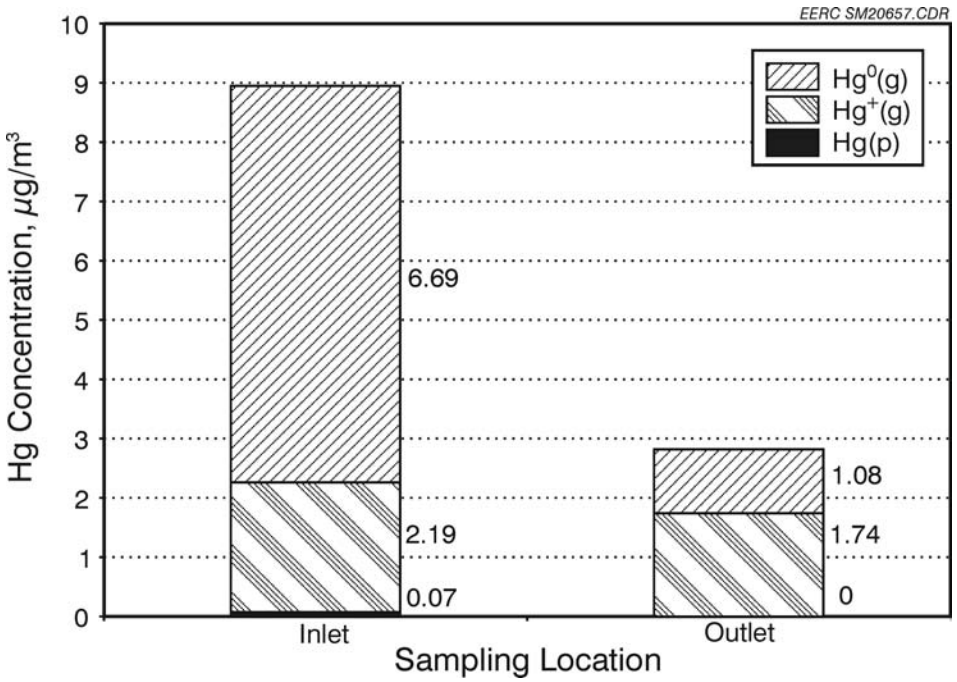

Figure 14. PTC-BA-629 – Test 3 – mercury species concentration in flue gas at the AHPC inlet and outlet (AHPC mode, 3.0 mA, 120-min residence time, 6000:1 carbon injection ratio).

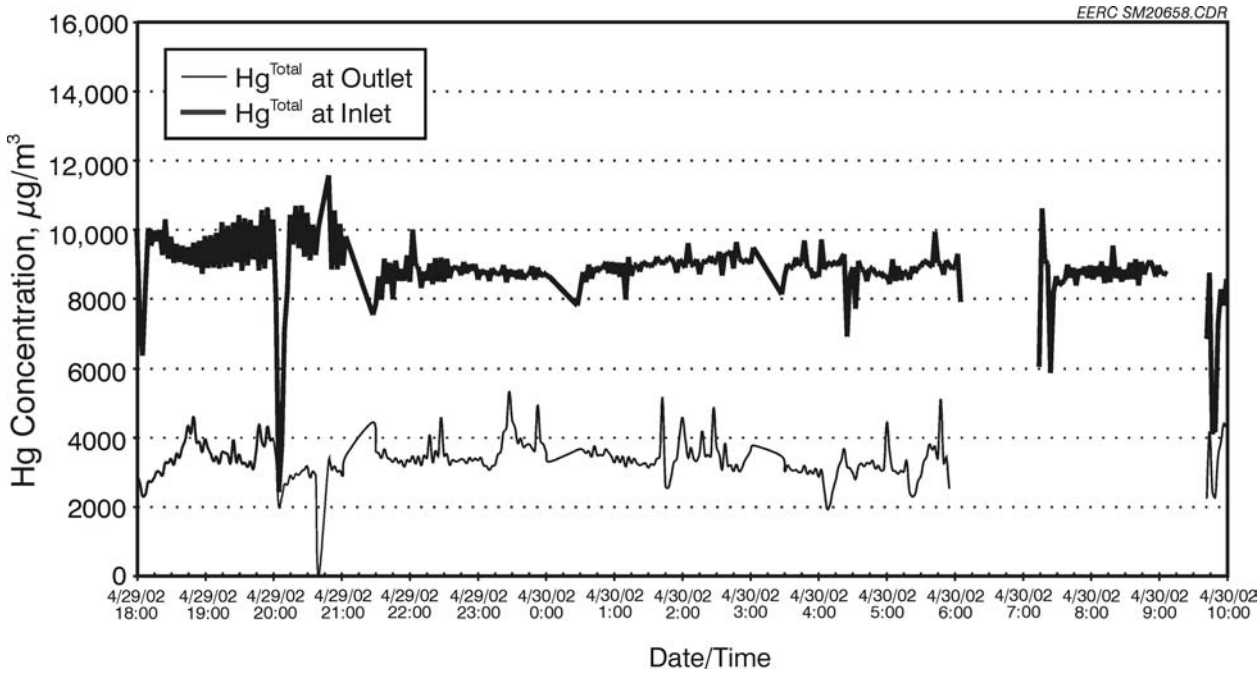

Figure 15. PTC-BA-629 – Test 3 – mercury monitor data.

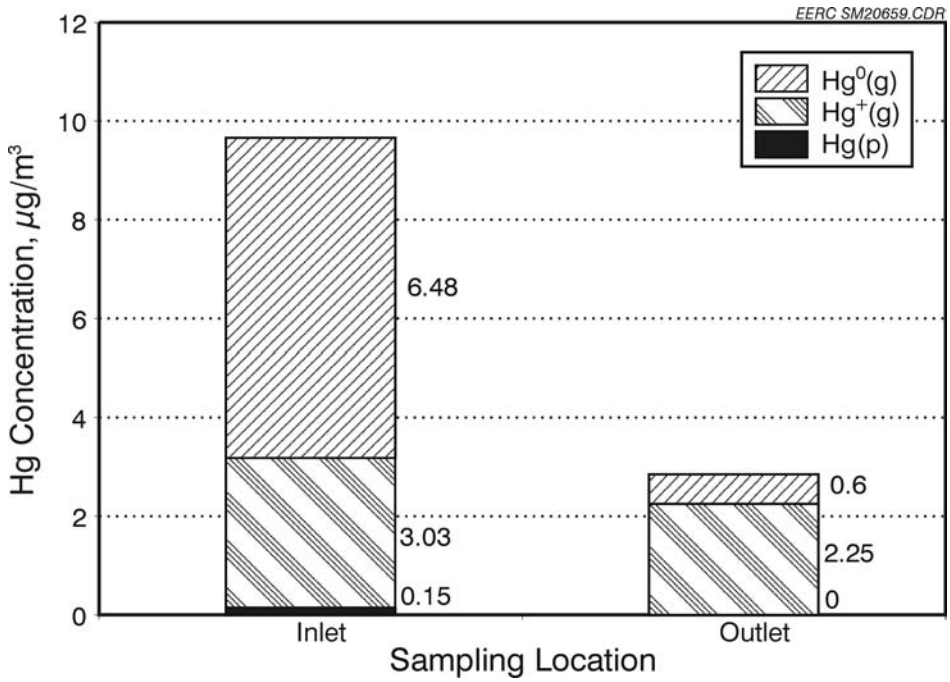

Figure 16. PTC-BA-629 – Test 4 – mercury species concentration in flue gas at the AHPC inlet and outlet (AHPC mode, 3.0 mA, 120-min residence time, 3000:1 batch power off).

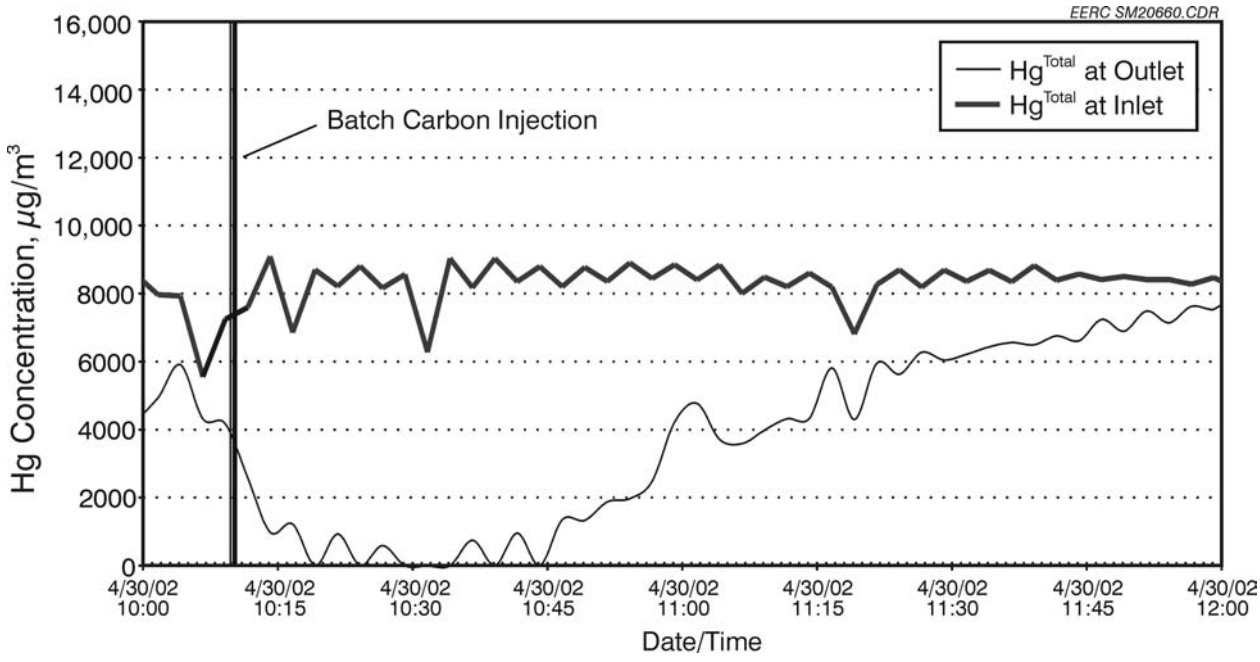

Figure 17. PTC-BA-629 – Test 4 – mercury monitor data.

3.2.8 Summary of Run PTC-BA-629

The removal efficiencies for the seven tests are shown in Figure 24. From these data, the removal efficiency is highly dependent on the carbon addition rate, but can be improved with batch injection. Over 70% removal was seen for all of the injection tests except for the last test. This suggests that the excellent mercury removal can be achieved with the AHPC, even for the difficult case seen here with very little natural capture of mercury by the fly ash and primarily elemental mercury at the inlet. To increase the capture above the 90% level will require further optimization of the AHPC and injection mode and may require a higher carbon addition rate or a more effective sorbent. Modification of the pilot-scale AHPC inlet configuration is expected to improve mercury capture by keeping more of the carbon in the main flow region within the AHPC housing.

3.3 Week 2 – Bituminous Coal Baseline, Run PTC-SC-632

For this test, Shade Creek bituminous coal was burned to establish baseline conditions. Coal analyses, including ultimate, proximate, mercury, and chlorine, are shown in Table 11. From the analyses, the theoretical mercury concentration in the flue gas is 17.6 $\mu g/m^3$ of dry flue gas corrected to 3% O_2. This compares with actual measured inlet total mercury concentrations in the range from 16.5 to 19.3 $\mu g/m^3$.

Three tests were completed under baseline conditions to evaluate the effect of residence time of the fly ash in the AHPC and to compare AHPC mode with pulse-jet mode (Table 12).

For Test 1, the AHPC current was set at 2 mA and the residence time was set at 30 min. Inlet and outlet mercury data from the Ontario Hydro sampling are shown in Figure 25. These data indicate 15.1 $\mu g/m^3$ oxidized mercury, 1.3 $\mu g/m^3$ elemental mercury, and 2.9 $\mu g/m^3$ particulate mercury. The two outlet samples indicate the largest fraction to be oxidized mercury with 1.1 to 1.9 $\mu g/m^3$ elemental. For Test 1, the data indicate no removal of mercury across the AHPC.

For Test 2, the AHPC was operated in similar mode except the hopper was not emptied for 24 hr. The Ontario Hydro data in Figure 26 indicate very different results compared to Test 1. At the inlet, almost all of the mercury was in particulate form and there was about 75% removal of mercury across the AHPC. If all of the inlet mercury was associated with particulate, it would be expected that it would all be captured in the AHPC. The outlet measured values of 3.8 and 5.0 $\mu g/m^3$ suggest that there may have been desorption of mercury from the inlet ash upon the long exposure to flue gas.

For Test 3, the unit was operated in pulse-jet mode without AHPC power and the hopper was emptied every 30 min. The inlet Ontario Hydro data in Figure 27 again show a high level of particulate mercury, with 2.8 $\mu g/m^3$ of oxidized mercury. The outlet data again indicate about 75% mercury capture across the AHPC.

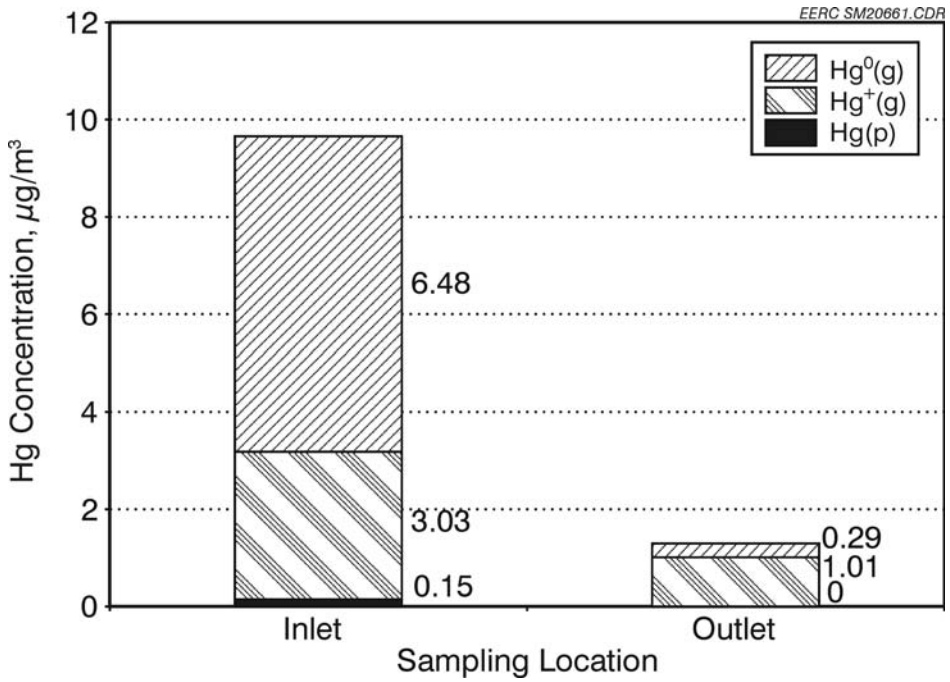

Figure 18. PTC-BA-629 – Test 5 – mercury species concentration in flue gas at the AHPC inlet and outlet (AHPC mode, 3.0 mA, 120-min residence time, 6000:1 batch power-off carbon injection).

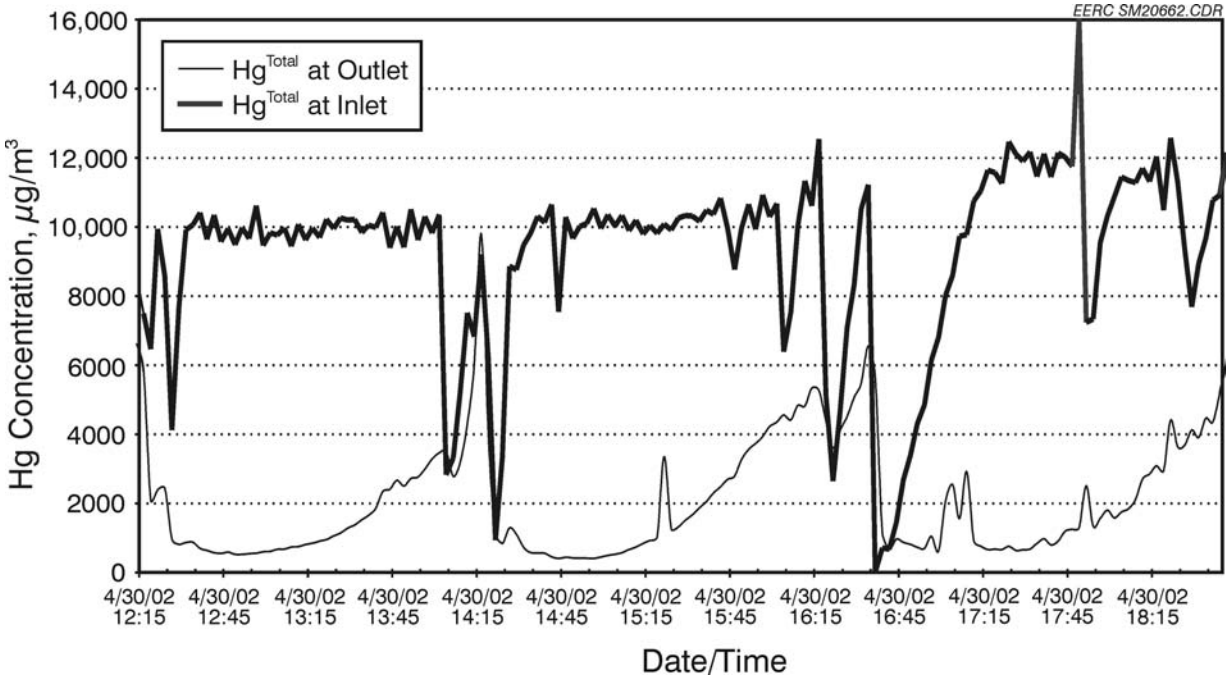

Figure 19. PTC-BA-629 Test 5 – mercury monitor data.

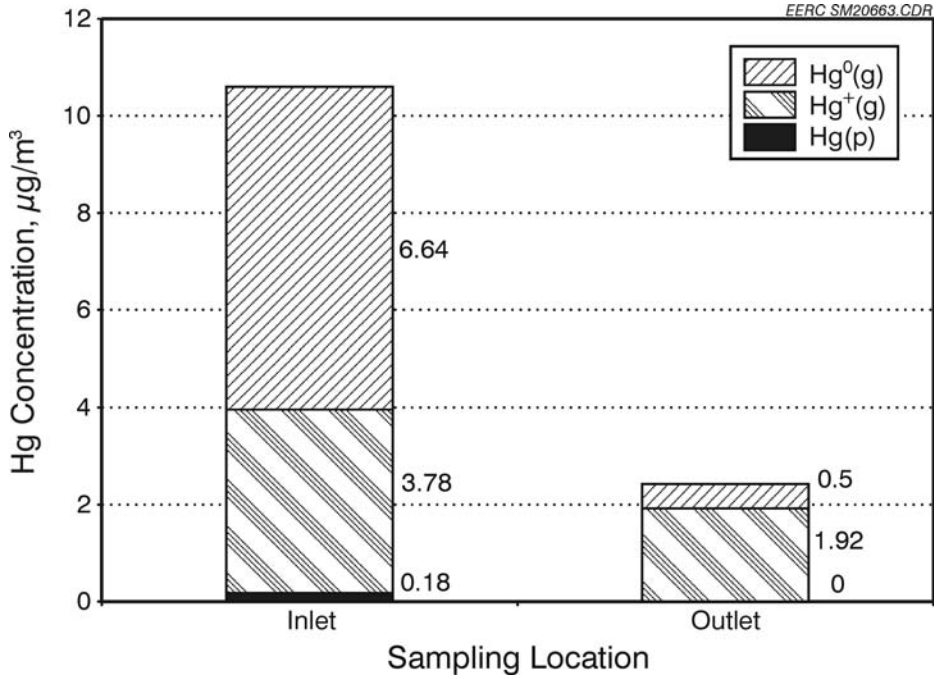

Figure 20. PTC-BA-629 – Test 6 – mercury species concentration in flue gas at the AHPC inlet and outlet (AHPC mode, 3.0 mA, 120-min residence time, 6000:1 batch power-on carbon injection).

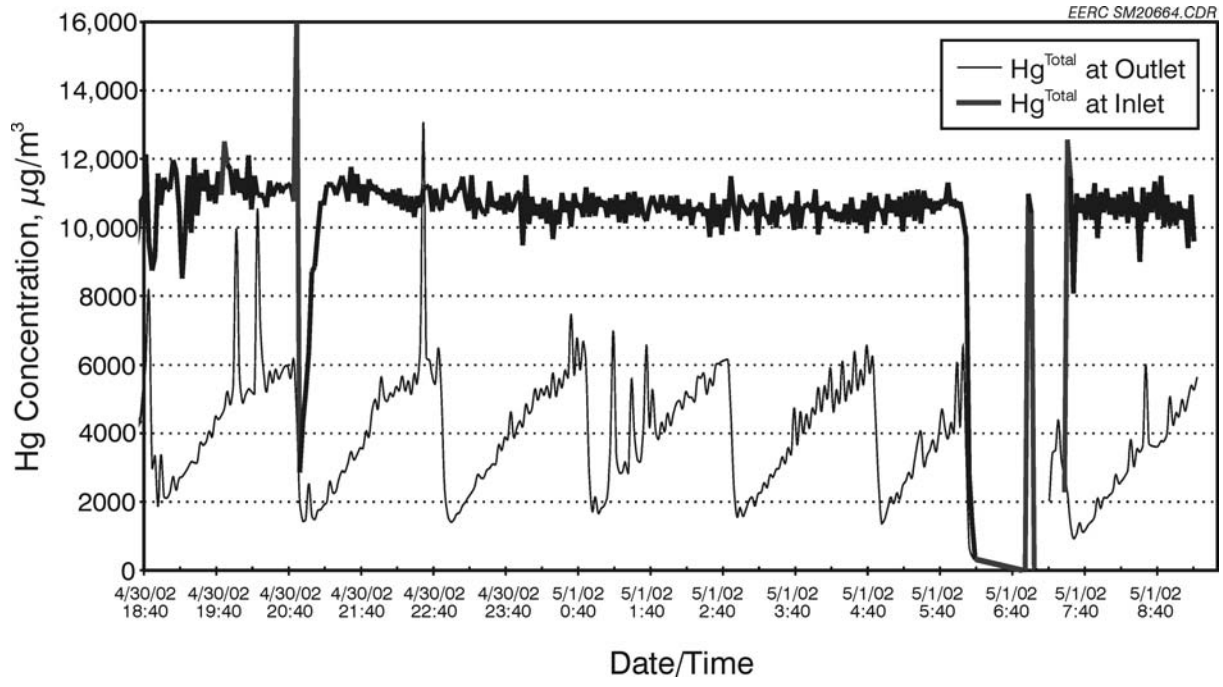

Figure 21. PTC-BA-629 – Test 6 – mercury monitor data.

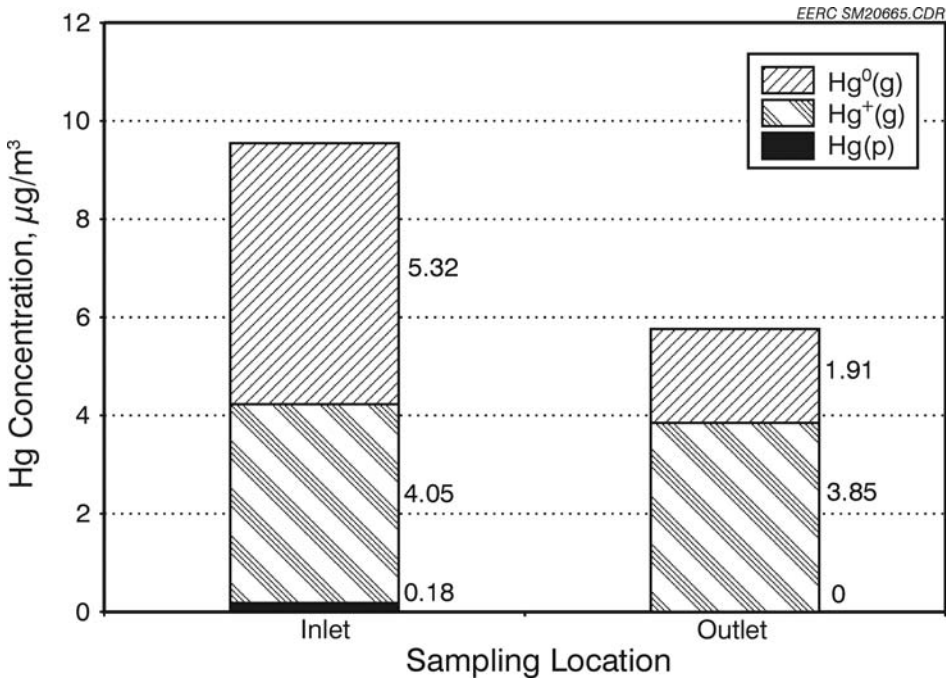

Figure 22. PTC-BA-629 – Test 7 – mercury species concentration in flue gas at the AHPC inlet and outlet (AHPC mode, 3.0 mA, 120-min residence time, 3000:1 continuous carbon injection).

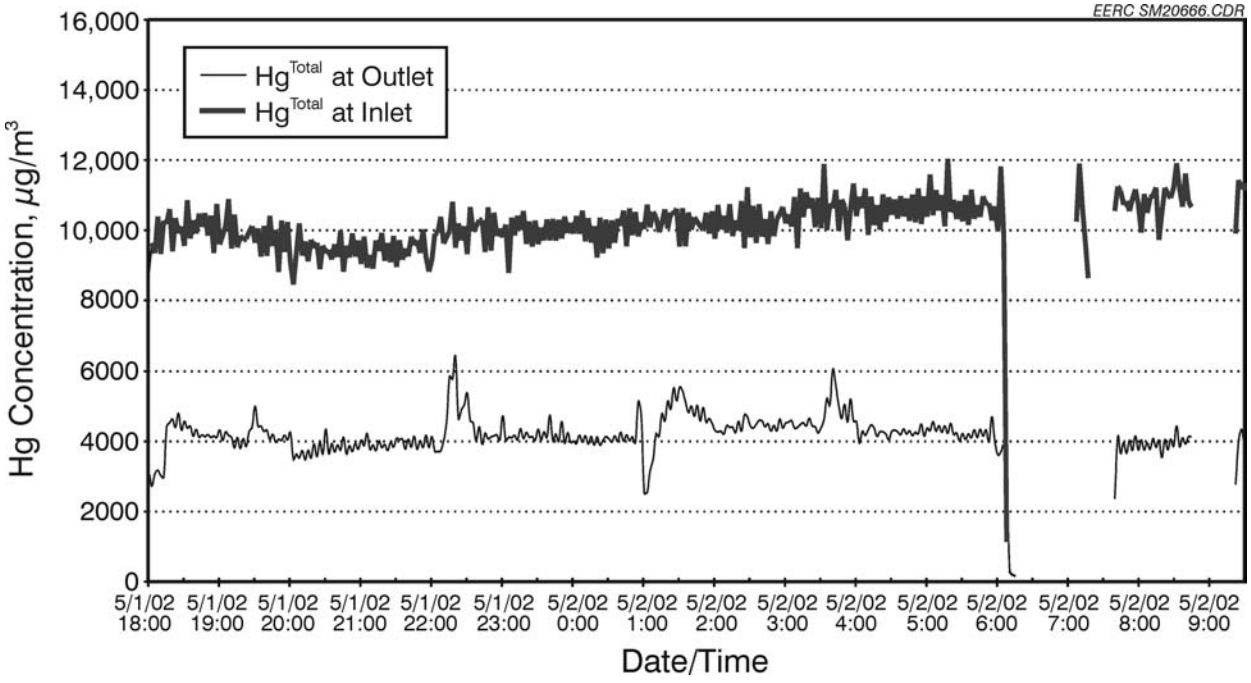

Figure 23. PTC-BA-629 – Test 7 – mercury monitor data.

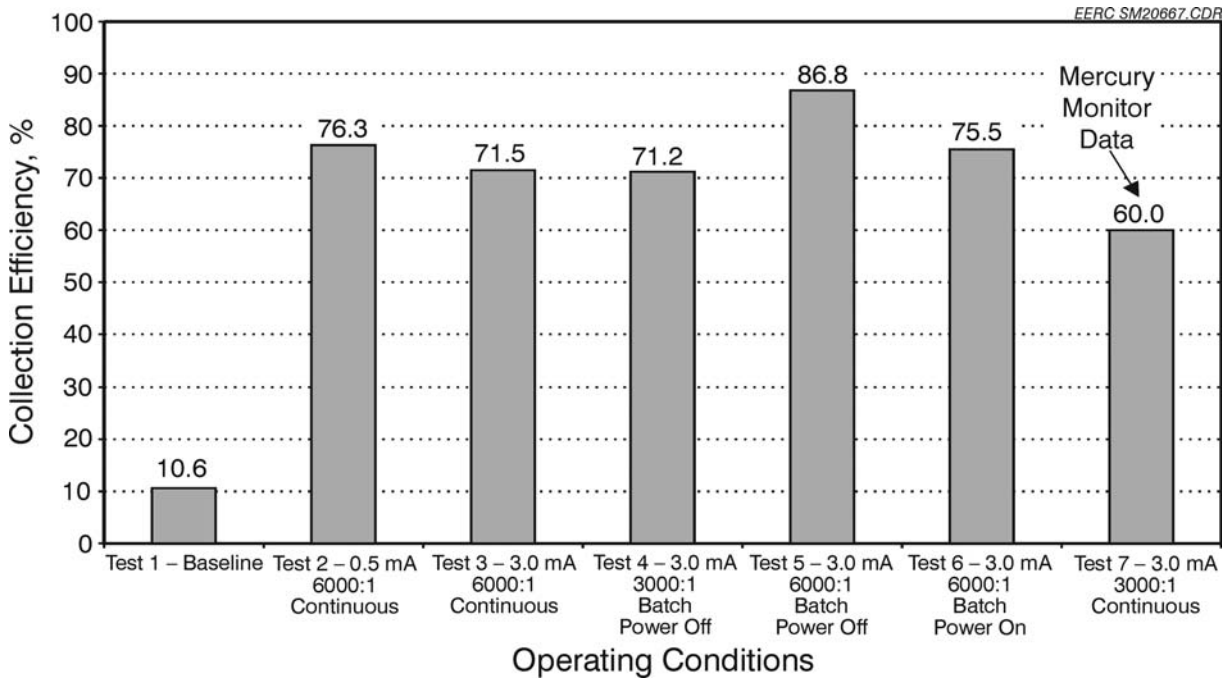

Figure 24. PTC-BA-629 – overall mercury collection efficiency by AHPC under different operating conditions.

Table 11. PTC-SC-632 – Coal Analysis

Proximate Analysis, %	As Sampled	Moisture Free
Moisture Content	2.1	NA
Volatile Matter	23.22	23.72
Fixed Carbon	63.1	64.46
Ash	11.57	11.82
Ultimate Analysis, %		
Hydrogen	4.46	4.32
Carbon	75.94	77.56
Nitrogen	1.64	1.68
Sulfur	1.45	1.48
Oxygen	4.93	3.14
Ash	11.57	11.82
Heating Value, Btu/lb	12,855	13,129
Chloride concentration, dry coal basis, μg/g		314
Hg Concentration, dry coal basis, μg/g		
Day 1		0.175
Day 2		0.18
Day 3		0.165
Mean		0.173

Table 12. PTC-SC-632 – Test Parameters

Test No.	Mode	Residence Time
1	AHPC 2 mA	30 min
2	AHPC 2 mA	>24 hr
3	Pulse jet	30 min

Obviously, there had to be some differences in the inlet ash to explain the differences between Test 1 and Tests 2 and 3. After completing the analysis of the hopper ash and the inlet filter ash, it became apparent that the differences were related to the amount of carbon in the ash. For the first inlet test, the inlet filter and hopper ash had similar mercury concentrations of about 0.35 μg/g and the loss on ignition (LOI) of the hopper ash was 10.85% (Table 13). However, the second hopper ash sample had almost five times more mercury, which corresponded to an LOI of 20.33%. For Test 2, again, the inlet filter and hopper samples had high mercury levels corresponding to 20.66% LOI. For Test 3, the results were similar, with a high ash mercury level and high LOI in the ash.

Past experience with this combustion unit has shown that typically bituminous fuel can be burned to produce fly ash with LOI in the range from 1% to 5%. However, because of the very high carbon and low volatile matter with this coal, good combustion in the pilot-scale unit to produce low LOI may be difficult without burner modification.

One purpose of this run was to serve as the source of flue gas for a bench-scale breakthrough test, but because of the high carbon in the ash and variable mercury concentration at the AHPC outlet, the fixed-bed tests could not be completed.

An interesting result from these tests is the relationship between the carbon content of the ash and the mercury retention. It might be expected that increasing the fly ash LOI from 10% to 20% would have a small impact on mercury retention. The significant effect in this case, however, suggests that the characteristics of the carbon may be as important as the amount of carbon.

Table 13. PTC-SC-632 – Mercury Concentration in Fly Ash

Test No.	Sample Type	Time Sample Taken	Hg Concentration, μg/g	LOI, %
1	Inlet Filter	6/03/02 14:00–16:00	0.362	
	Hopper ash	6/03/02 16:00	0.344	10.85
	Hopper ash	6/04/02 7:00	1.64	20.33
2	Inlet Filter	6/05/02 8:27–10:27	2.19	
	Hopper ash	6/05/02 11:00	1.48-1.63	20.66
3	Inlet Filter	6/05/02 14:00–16:00	1.55	
	Hopper Ash	6/05/02 16:00		21.59

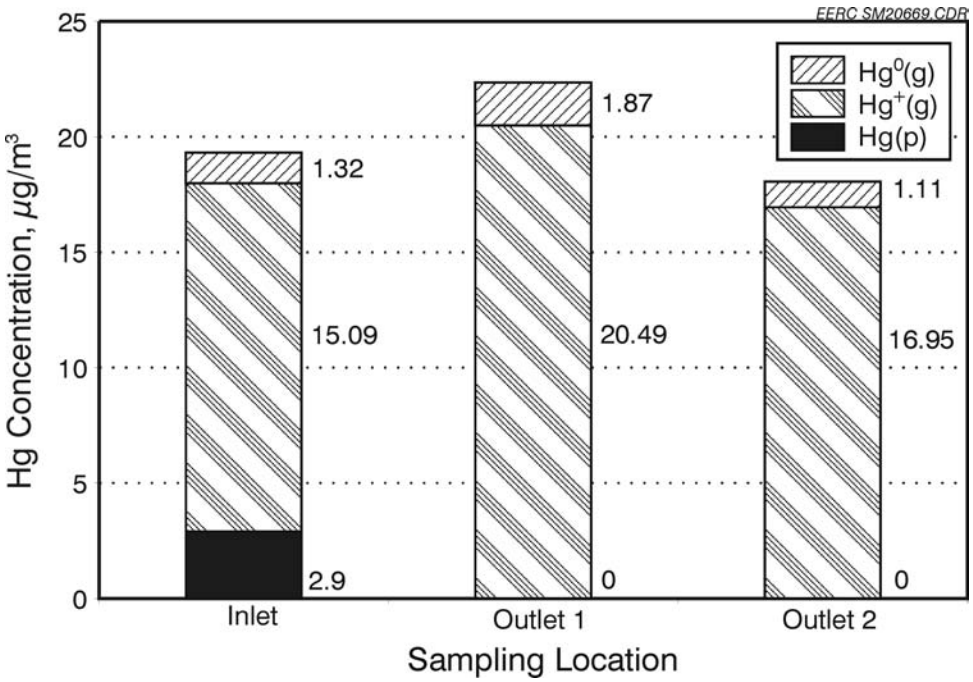

Figure 25. PTC-SC-632 – Test 1 – mercury species concentration in flue gas at the AHPC inlet and outlet (AHPC mode, 2.0 mA, 30-min residence time).

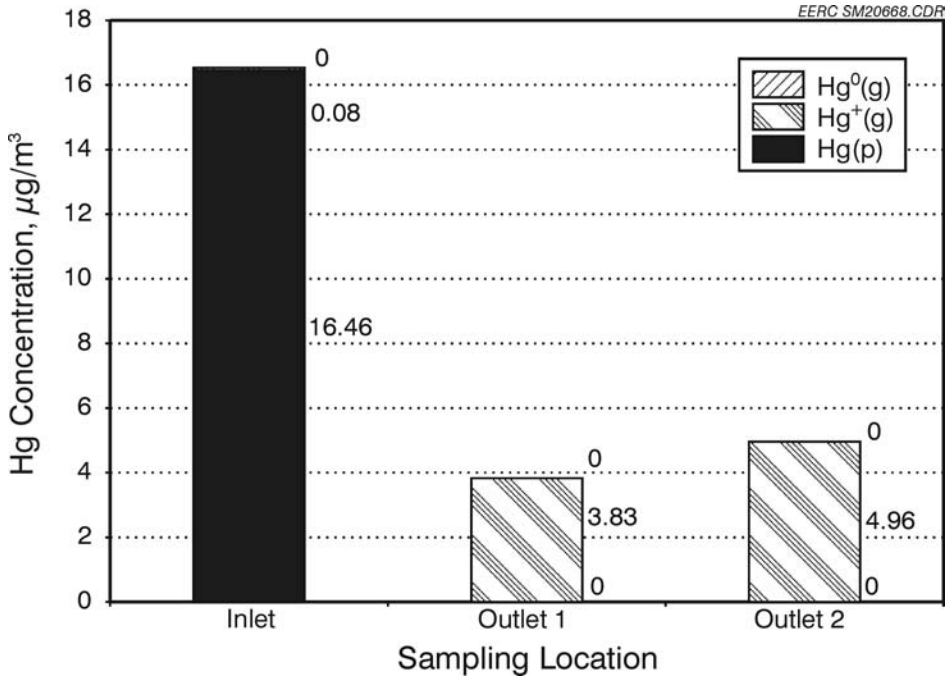

Figure 26. PTC-SC-632 – Test 2 – mercury species concentration in flue gas at the AHPC inlet and outlet (AHPC mode, 2.0 mA, 24-hr residence time).

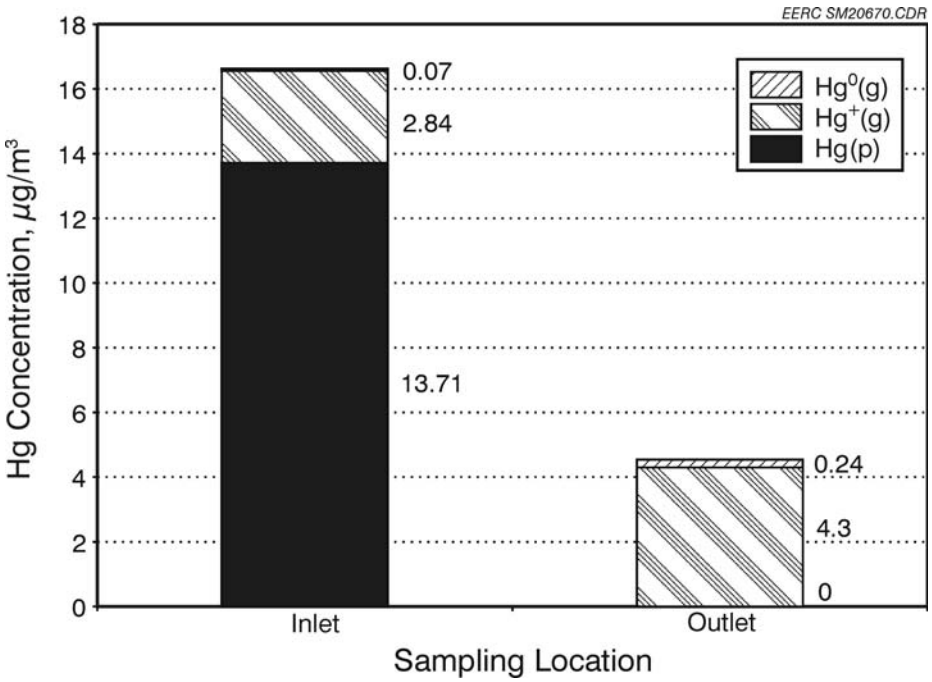

Figure 27. PTC-SC-632 – Test 3 – mercury species concentration in flue gas at the AHPC inlet and outlet (pulse-jet mode, 8.0 in. W.C. pulse trigger pressure, 60-min residence time).

Evidently, the additional carbon that was present in the ash for Tests 2 and 3 had the ability to capture mercury while the carbon from Test 1 did not have the same characteristics.

At this time, the decision has not been made whether to repeat these tests after burner modification or to select another bituminous coal with a higher volatile matter content.

4.0 CONCLUSIONS

- A number of baseline and carbon injection tests were completed with Belle Ayr PRB subbituminous coal. For the baseline case, approximately 70% of the inlet mercury was elemental, approximately 23% oxidized, and 2% or less was associated with particulate matter. There was very little natural mercury capture across the AHPC for the baseline tests and only a slight increase in the level of oxidized mercury across the AHPC during baseline operation.

- With carbon injection, a comparison of short and long residence time in the AHPC showed that somewhat better mercury removal was achieved with longer residence time. No evidence of desorption of mercury from the carbon was seen upon continued exposure to flue gases up to 24 hours. This suggests that desorption of captured mercury from the carbon sorbent is not a significant problem under these flue gas conditions with the low-sulfur subbituminous coal.

- At a carbon-to-mercury ratio of 3000:1, from 50% to 71% total mercury was achieved. When the ratio was increased to 6000:1, the removal increased to the range from 65% to 87%. These results are highly encouraging, because this level of control was achieved for the very difficult case with predominantly elemental mercury and very little natural capture of mercury by the fly ash.

- Observation of the flow patterns within the pilot-scale AHPC showed that a significant fraction of the sorbent was collected on the outside walls of the vessel rather than the perforated collection plates and filter bags, resulting in a situation where a fraction of the sorbent was directed away from the main gas flow region. Reducing the corona current somewhat improved the collection efficiency, but collection on the outside walls was still evident. Modification of the inlet configuration so the flow is directed between the discharge electrodes and perforated plates would likely minimize the problem and improve the gas–solid contact within the pilot-scale AHPC. This problem is unique to the small-scale pilot unit with a single row of bags and is not likely to be significant in a larger-scale AHPC.

- A comparison of batch injection of sorbent with continuous injection showed that mercury removal was improved with the batch injection. Tests with batch injection comparing power off with power on showed that 87% removal was seen when the power was momentarily shut off during injection compared to 75% removal with power on batch injection. The power-off injection should result in most of the sorbent reaching the filter bag surface where the best gas–solid contact is thought to occur. However, during the power-on injection, a fraction of the sorbent collected on the outside walls. With a modified inlet configuration, the benefit of power-off injection may be negligible.

- During the power-off batch injection cycles, the mercury removal was well over 90% for the first half of each cycle. This is encouraging because it indicates that over 90% removal is possible with the low-cost FGD sorbent and that with further optimization 90% control should be achievable, even for a coal that produces mostly elemental mercury and with little natural mercury capture in the fly ash.

- A baseline test with an eastern bituminous coal resulted in LOI levels in the fly ash from 10% to 20%. At the 10% carbon level, there was minimal capture of mercury by the fly ash, but at 20% most of the mercury was retained by the fly ash. This suggests that the relationship between the amount of carbon in the ash and the level of mercury capture is complex and may depend more on critical carbon characteristics than on the amount of carbon present.

5.0 REFERENCES

1. Zhuang, Y.; Miller, S.J.; Olderbak, M.R.; Gebert, R. *Advanced Hybrid Particulate Collector – Phase III*; Final Report for U.S. Department of Energy National Energy Technology Laboratory, Sept 2001.